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Effects of Cover Crop Treatments on Apple Trees

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Abstract

Ground cover management systems affect soil quality and health and thereby orchard growth and productivity. There have been few studies in the southern US on the effects of managed drive-rows using cover crops as part of a sustainable apple orchard management system. A field study used treatments of 1) seasonal legumes (cowpea [*Vigna unguiculata*] and crimson clover [*Trifolium incarnatum*]), 2) seasonal grasses (millet [*Setaria italic*] and annual rye [*Lolium multiflorum*]), or 3) unmanaged natural vegetation drive row plantings, with mowed vegetation blown into the tree row as mulch (mow/blow) nested variable. The legume crop cycles produced more than twice as much cover crop tissue N than grasses or natural vegetation. Soils with legume mulches produced the highest labile N compared to other treatments, and the highest labile N where legumes were mulched to the tree-row with a mow/blow treatment. There was a smaller labile pool C/N ratio for legume treatments and for tree row compared to drive row samples, and the largest N concentration for soils in the tree row with legumes as a mow/blow mulch. After two seasons the labile pool C/N ratio was lower for legumes than other treatments. Tree foliage, had highest N content for the legume treatments. These results indicate that legume cover crop mow/blow management systems may offer a N benefit and be a potential sustainable alternative for orchard management. A greenhouse study was also conducted, pairing the cover crop species of the field study with potted apple trees to examine the effects of both cover crop competition and mulches on tree growth and nutrient status. Apple trees in inert media were grown with and without cover crop competition, and cover crops were cut and mulched to the media surface. Cowpeas and German foxtail millet were studied. Legume cover crops generated more biomass per plant, higher % and total N, and total C. Trees grown in competition with cover crops grew less than those without, and did not recover after cover crop harvest within the

duration of the study. Trees with neither mulch nor competition grew better than either competition treatment.

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Abbreviations used in Chapter 2

A = Leaf CO_2 assimilation as net photosynthetic rate

C_i = Intercellular leaf CO_2 concentration

CP = cowpea competition

CPM = cowpea mulch

Et = plant evapotranspiration water loss

FM = millet competition

FMM = foxtail millet mulch

gs = stomatal conductance

NT = non-treated control

Abbreviations used in Chapter 3

BD = bulk density

OM = organic matter

TCSA = tree trunk cross-sectional area

VWC = volumetric water content

Introduction

Sustainable agriculture, as a relatively new discipline (Harwood, 1990), deserves and requires research. With an expanding human population requiring greater agricultural productivity, a popular response is to increase production inputs, e.g. more fertilizers and more pest control chemicals (Cassman, 1999). The manufacture of fertilizers raises environmental concerns. In addition, fertilizer manufacture requires use of finite natural resources, both mined and drilled. Therefore, alternatives to crop nutrition while maintaining soil biological activity and quality are needed.

Sustainable agriculture seeks to solve problems in ways that can reduce inputs while improving soil health and crop health while protecting both human and environmental resources (Feenstra et al., 2015). According to the US Congress, sustainable agriculture is "an integrated system of plant and animal production practices having a site-specific application that will, over the long-term- A) satisfy human food and fiber needs; B) enhance environmental quality and the natural resource base upon which the agricultural economy depends; C) make the most efficient use of non-renewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls; D) sustain the economic viability of farm operations; and E) enhance the quality of life for farmers and society as a whole." (U.S. Code Title 7, Section 3103).

The basic tenets of the sustainable agriculture movement include producing food without natural resource depletion; water quality protection both on and off the farm; farm biodiversity improvement; minimal use of chemicals; and ecological pest management. While conventional agriculture is largely production and profit driven, sustainable agriculture brings together many sciences to develop new methods of agricultural production that do not degrade the environment

(Lichtfouse, 2009). A central focus of sustainable agricultural systems is management of soil health. Lal (2009) notes that prior to the latter half of the 20th century, the focus of soil science was primarily on increasing productivity, but that solutions to issues of land degradation, water system contamination (and eutrophication), and climate change lie in sustainable management of soils. To this end, the adoption of conservation tillage practices (Franzluebbers, 2004), cover cropping, and careful crop rotations (Seiter and Horwath, 2009) as means of maximizing production while slowing or reversing the depletion of soil nutrients through maintenance of soil organic matter are useful approaches. There are numerous recognized benefits to using cover crops in an agricultural production cycle. Cover crops are plantings that are not the cash crop grown for direct production or harvest but are grown for various purposes to benefit the primary crop, including for erosion control and for biomass additions contributing organic biologically fixed nitrogen to soils (Magdoff and Van Es, 2009). Additionally, cover crops reduce agricultural runoff by tying up excess nutrients that would otherwise end up migrating to groundwater (Seiter and Horwath, 2009). Ladha and Peeples (1994) suggested that in fact some crop yield increases attributed to a rotation with nitrogen-fixing cover crops may in fact be due as much to the benefits of breaking the disease and pest cycles and improvement of soil microfauna as it is to the addition of biologically fixed nitrogen by that cover crop.

The majority of the use of and research into cover crops has been related to annual cropping systems, where cover crops are grown as part of a rotation in which the cover crops are killed and incorporated into the soil prior to economic crop planting (Colla, 2000; Parr et al., 2011). Another approach, in conservation tillage or no-till systems, is to grow an off-season cover crop. The cover crop is then cut or desiccated with herbicides and the major crop planted directly into the remains. Alternatively, cover crops have been planted between the rows of the major economic crop. Although considerable research has examined the use of cover crops in annual vegetable cropping systems, less has been done with perennial horticultural systems such as orchards. Some research has been conducted using cover crops within orchard tree rows for weed management and/or potential nutrient contribution (Atucha et al., 2011; Mays et al., 2014; TerAvest et al., 2010), but even less in using them as drive row plantings between tree, shrub, and vine rows (Granatstein and Sanchez, 2009).

Sustainable orchard management has gained traction as an approach to conserve resources, improve the soil and environment, and provide viable commercial fruit crops while being socially responsible. Among the management considerations are reduced machinery use, minimized frequency of pest control sprays, reduced pesticide use, and managing tree nutrition with minimized synthetic inputs. The management goal is to develop a system beneficial to the health of both the trees and the quality and health of the soil in which they grow (Reganold et al., 2001).

Nutrient management is of particular concern in growing apples. Nitrogen is generally considered the limiting factor in tree growth and fruit production. Therefore, seeking ways to provide sufficient N to apple trees with the appropriate delivery time has been the topic of some, but insufficient, research (Granatstein and Sanchez, 2009). Multiple studies have shown that apple trees perform poorly with competitive vegetation (Atkinson et al., 1977; Atucha et al., 2011); therefore, the standard management approach in conventional orchards is to maintain a weed-free strip under the trees, achieved by repeated application of long-residual herbicides. Often, this is complemented by a marginally managed grass drive alley. In organic systems, the primary management practice is surface cultivation of the tree-row soil for weed management, and a grass alley. Some orchardists use a different approach, in which the drive-alley is planted in leguminous cover crops, or mixes of legumes and grasses which get mowed periodically and are assumed to provide N to the trees.

The studies conducted on this subject have in many cases failed to isolate single crops. Instead, researchers have evaluated cover crop mixes, which make assessment of specific contributions difficult, or they have cut and dropped the crop in the drive alley (Sánchez, et al, 2006). Others have examined cover crops as living mulches in the tree row (Hoagland, et al., 2008; Merwin and Stiles, 1994; TerAvest, et al., 2010; Yao, et al., 2005). The bulk of cover crop research has focused on annual cropping systems and the use of cover crops as green manure or other techniques not entirely applicable to perennial crops. The potential of N-fixing cover crops in apple orchards has not been assessed thoroughly.

Chapter 1: Literature Review

Cover Crops for Horticultural Applications

Role and Functions: Cover crops can provide weed control (Nelson et al., 1991), nutrient production through nitrogen-fixing legumes, nutrient scavenging and the reduction of fertilizer runoff and leaching, the moderation of soil moisture and temperature extremes (Atucha, 2011), habitat for beneficial insects which may provide pest suppression (Snapp et al., 2005), and organic matter for soil improvement in the form of green manures or mulches. The addition of mulches and other organic amendments to the tree root zone results in improved productivity (Hogue and Neilsen, 1987). Using cover crops for mulching reduces the rate of evaporation of moisture from the soil and improves soil physical and biological properties (Fageria, 2005). Since apple orchards are often on steep terrain, soil erosion management is often a concern, and compared to bare ground, cover crops significantly reduce erosion and improve soil structure (Ruiz-Colmenero et al., 2013; Miller et al., 1989).

In annual cropping systems, cover crops are generally grown at times when a field would otherwise lie fallow, such as following the primary cash crop or in between cash crops (Magdoff and Van Es, 2009), serving multiple soil building functions as well as providing erosion control. However, perennial systems present different considerations. In apple orchards, cover crops can be planted in the drive alleys between tree rows, allowing simultaneous cover crop and cash crop production but potentially requiring further management to provide tree roots access to decomposing cover crop nutrients. One of the primary functions of an orchard alley is to withstand equipment and machinery passing through for spraying, mowing, and harvesting, so a cover cropped alley must, in addition to other functions, provide mechanical stability (Tworkoski and Glenn, 2008).

Putnam et al. (1983) reported that the crop residues from rye cover crops could suppress weed growth for up to 6 weeks after harvest and application. Other studies have also demonstrated a weed suppressive function from cover crops. Nelson et al. (1991) found that crimson clover was preferable to perennials such as white or red clover as spring cover crops but concluded that annual rye was one of the best cover crops for weed suppression. Researchers have also examined weed suppression capabilities of leguminous cover crops during growth stages. Creamer and Baldwin (2000) concluded that the greater the biomass of the cover crop, the better the weed suppression during growth.

Problems associated with cover crops**:** Species choice and management practices become critical in using cover crops in orchard systems, as many potential issues can arise, and the body of research does not yet provide a full picture of best management practices. Adding another plant species to the orchard ecosystem can introduce or attract different pests and nematodes, provide shelter for rodents, introduce allelopathic interaction (Adler and Chase, 2007), and compete with tree roots for nutrients and moisture. Studies using cover crops as a green manure in the tree row (Hoagland, et al., 2008; Sanchez, et al., 2003) have shown that root-zone competition inhibits tree growth and results in fewer roots, less overall growth, and altered distribution of roots.

Insect populations vary by plant species, and care should be taken to choose species that do not harbor pests that could pose serious cash crop management issues. Sometimes this can be handled by harvest time- for example, cowpeas may attract stinkbugs but not until seed pod formation (Abudulai et al., 2003). When used as a cover crop, cowpeas are harvested well before seedpod maturity, eliminating that potential problem. Conversely, cover crop species which are more attractive to a given pest than the cash crop could be grown, thus functioning as a trap crop (Bugg and Waddington, 1994).

A concern is that cover crop use may encourage the presence of meadow voles (*Microtus pennsylvanicus*). Wiman et al. (2009) grew cover crops as a living mulch in the tree row, and found significantly higher vole populations in a treatment of mixed leguminous crops when compared to bare ground or wood chip mulch, and somewhat higher populations when compared to non-leguminous cover crop mixes. An increase in vole presence in living mulch systems was also observed by Granatstein and Sánchez (2009). White clover planted as a perennial living mulch in the tree row resulted in a significant increase in vole populations. (Mullinix and Granatstein, 2011). Likewise, Ingels (1994) noted that perennial clovers are known for increasing gopher populations.

Some frost management issues may accompany cover cropped orchards, as temperatures tend to be lower than bare ground (Miller, 1989). This can be managed in perennial crop systems by close mowing around frost events, but presents more of an issue with annual cover species if crop cutting time does not coincide with frost risk periods.

Planting cover crops in the orchard drive row can create some management issues when comparing to bare soil. Having another crop in the orchard may cause rapid moisture depletion during dry seasons as that crop uses available soil water. Soil water deficit has been significantly greater in grassed alleys than in herbicide strips by midsummer (Atkinson et al., 1977). However, an annual grass/legume cover crop had a higher soil water content as compared to permanent grass in the drive-row alleys (Kuhn and Pederson, 2003). How much of a management issue these differences present may be dependent on local climate and weather patterns as well as the width of the tree-row herbicide strip, irrigation systems, and soil structure.

Cover crops (as opposed to bare soil) will also slow the warming of soil in the spring. O'Connell and Snyder (1999) found that cover crops and mulches in citrus orchards in California decreased nighttime temperatures by 0.5-1.2 C, which could bring an increased risk of freeze damage from late spring frosts. Additionally, broadleaf crops could create pest and disease habitat that may be detrimental to the fruit crop. Mullinix and Granatstein (2011) concluded in a study that perennial plantings in the tree row made it difficult to control timing of N release to trees Using cover crops in the orchard can create more monitoring and management work, increased costs (Ingels et al., 1994) from the seeding, timed cutting, and reseeding of cover crops as well as potentially additional pest management costs.

Potential for improving soil nutrient levels and plant nutrient status with cover crops: The rising costs of nitrogen fertilizers (Mullinix and Granatstein, 2011) coupled with concerns about nitrate leaching into groundwater (Fallahi et al., 1997), has created a need for viable alternatives, particularly for organic growers, but uncertainty about the actual N contributions of cover crops (as well as concerns over increased pest management problems) has prevented widespread adoption. Crops that biologically fix atmospheric nitrogen can provide a source of orchard tree nutrition. Additionally, many crops, particularly cereals, are excellent nutrient scavengers and can aid in the recycling of orchard nutrients and prevention of runoff and groundwater losses, particularly of N (Tagliavini and Millard, 2005; Delgado et al., 2007).

Cover crops that biologically sequester N: Research has shown that significant N can be derived from cover crops. In annual systems, as much as 94% of nutrients taken up by crops end up being removed at harvest, whereas in apple orchards, fruit removal and pruning may account for 10-50% of nutrient uptake (Faqi et al., 2008). Winter legumes can add 112-224 kg N/ha, and cowpea and other summer legumes can contribute 112-145 kg N/ha to the soil nitrogen pool. (Ingels, 1994). Ladha and Peoples (1994) reported inputs of N from N fixation between 124-185 kg/ha for crimson clover, and 9-201 kg/ha for cowpea. Wagger (1989) reported crimson clover nitrogen fixation of 100-150 kg/ha, and Odhiambo and Bomke (2000) concluded that crimson clover could provide the rapid release of enough nitrogen to sustain the growth of crops. Legumes, due to a low C:N ratio, decompose quickly, and best results may result from mixing grasses and legumes (Fageria, et al., 2005). Mixing leguminous cover crops with cereals could slow the N immobilization that cereals cause while delaying the release of N from crimson clover (Odhiambo and Bomke, 2000). However, nodulation and subsequent N fixation are negatively affected by low phosphorus concentrations and low pH (Atkinson et al., 1977).

Cover Crops and Drive Row Middles for Orchards

Methods of managing orchard floors: In conventional orchard systems, the tree row is maintained weed-free through herbicide use. Numerous studies have demonstrated that eliminating competition from the tree root-zone results in better growth and yield (TerAvest et al., 2011, Tworkoski and Glenn, 2012). The most common organic option for weed control is clean cultivation (TerAvest, 2010), often achieved with a Weed Badger or similar equipment, which while effectively controlling weeds can also inflict damage to the tree trunks and is unsuitable for young trees. Cultivation is labor-intensive, damages soil quality, and reduces N availability through a faster breakdown of OM and volatilization of soil N (Granatstein and Sanchez, 2009). Additionally, there is considerable documentation of the detrimental effects of long-term orchard floor cultivation and/or herbicide use (Hogue and Neilson, 1987, Hipps and

Samuelsen, 1991). Many other orchard understory management approaches have been examined, each with its own advantages and disadvantages. Landscape fabric provides effective and long-term weed control but is expensive, creates a barrier through which various biota cannot pass, and may encourage rodent populations (Merwin, 1995).

Trees grown with mulch instead of grass, herbicide strip, or cultivation, produce more roots (Gurung, 1979). The root system in high-density apples tends to be mostly vertical sinkers with few horizontal roots, and as tree spacing decreases, root density increases (Gurung, 1979). Atkinson (1980) concluded that grass cover crops in the tree row competed with tree roots. The majority of apple roots remained in the tree row when using an herbicide strip/grassed alley combination (Atkinson, 1980). Labeled N uptake in mature trees from the grassed alley was very small compared to within the herbicide strip, and Atkinson (1980) proposed that this may in part be due to differences in soil water potential.

Although the long-used method of clean cultivation in orchard alley management eliminates alternate pest hosts, removes the potential for temperature moderations from vegetative cover, and simplifies orchard floor management, there are numerous potential drawbacks to this system. Soil organic matter was decreased by cultivation, and soil OM improves soil structure, allowing for better water infiltration, improved tilth, and increased available nutrients (Miller et al., 1989). Organic matter can be added through the use of cover crops, and its loss is hastened by clean cultivation.

A mow/blow treatment from drive alley to tree row resulted in 20% greater soil C when compared to herbicide tree row (Sanchez et al., 2003). However, one potential concern of ongoing mow/blow treatment may be that P and K are being constantly relocated, causing deficiencies in the drive row and potential overload in the tree row (Granatstein and Sanchez, 2009). In contrast, mulching to the tree row using ryegrass, clover, and herb ley improved soil N, P, K, Ca, pH, and organic C with few differences between treatments (Marsh et al., 1996). Nielsen and Hogue (2003) also reported that tree-row mulches of various types all improved soil nutrition coupled with maintenance or improvements in crop productivity. However, crop choice can affect results - in one study, a red clover mow/blow treatment resulted in N release mid-season, reducing fruit quality (Marsh et al., 1996).

<u>Characteristics of drive-row cover crops for orchards:</u> In addition to nutrient management, one of the major problems in organic and sustainable orchard systems is weed control. In conventional orchards, a weed-free strip is maintained in the tree row with herbicide applications and a grassed alley (Roper, 1992); however, for organic growers, the most commonly employed option for orchard understory is clean cultivation (Pavek, 2014; Teravest et al., 2010).

There are compelling reasons to use annual cover crops even in a no-till orchard system. Perennial clovers result in increased rodent populations (Mullinix and Granatstein, 2011; Ingels, 1994). Employing crop rotations in which periods exist with no actively growing drive row vegetation can assist in breaking or preventing pest and disease cycles that may be associated with permanent cover crops.

When comparing annual grass/legume cover crops to permanent grass and permanent clover/grass, the annual system resulted in greater tree growth and greater leaf N, fruit yield, and water content in the drive row (Kuhn and Pederson, 2003). Furthermore, employing a mow/blow mulching treatment to transfer clippings to the tree row resulted in higher yield of better colored fruit compared leaving clippings in the alley way (Kuhn, 2003).

Impacts of cover crops in orchards: One function of a cover crop grown on site and managed in a mow/blow system can be to serve as a mulch for the apple trees. The beneficial value of mulches to apple trees has been documented - they conserve moisture, moderate soil temperature fluctuations, suppress weeds, add nutrition, and help control erosion (Skroch and Shribbs, 1986).

A number of studies of cover crop use in apple orchards have focused on tree understory, and the impacts of cover crop growth within the tree root zone (Hoagland et al., 2008; Merwin and Stiles, 1994; Neilsen and Hogue, 1985; and Sanchez et al., 2003). When studying newly established orchards, the competition between cover crop (of any type) and apple tree resulted in reduced trunk cross-sectional area and fruit yield as well as decreased leaf nitrogen levels (Merwin and Styles, 1994). In 10-year-old trees, Tworkoski and Glenn (2012) used various grasses as a tree understory to suppress other weeds and recorded little adverse effect on the trees. Comparing standard tillage practices for understory management to alternative management options, a living mulch understory increased both soil nitrogen and biological activity but reduced tree growth compared to other treatments (Hoagland et al., 2008). Sanchez et al. (2003) studied mature cherry trees and found no reduction in vigor or production from a living ground cover understory.

Given the current trend in high-density orchards, where closely planted trees can come into production in two to four years, using cover crops within the tree row may not prove to be a viable option, but there is little literature examining the effects on mature high-density plantings on size-controlling rootstocks. Drive row plantings may offer viable alternatives for nutrient and biomass additions without competition and using a mow-blow approach could assist with, although not provide a total solution for, weed management within the tree row.

Nutrient Requirements, with a Focus on N, for Apple Orchards

Nutritional needs and ranges: Nutrient deficiencies in apple orchards are often best determined through apple foliar analysis. Optimal levels of foliar nitrogen range from 1.8% to 2.6% depending on the maturity and productivity of the tree, phosphorus should be 0.13-1.33%, and potassium 1.35-1.85% (Stiles and Reid, 1991). Campbell (2009) considers apple foliar N levels of 1.9%-2.3% as normal range. Although phosphorus and potassium may need to be added during establishment phases, by maturity, nitrogen becomes the primary nutrient requiring close monitoring of availability and uptake. Other nutrients for which it is worth recognizing deficiency symptoms are boron, iron, zinc and sulfur (Benson, et al., 1994). Foliar nutrient status can vary by rootstock, interstem, and cultivar.

Holb et al. (2009) conducted a study comparing apple nutrient status in organic and integrated management systems and concluded that the more readily absorbable nutrients in synthetic fertilizers resulted in better nutrient uptake in the integrated system. Greenham (1980), in studying nutrient budgets in apple orchards, proposed that most nutrient needs of apples, which are lower than most annual vegetable crops, can be met by organic matter decomposing in the soil. To maintain sufficient nutrient levels would require the replenishment of organic matter on an annual basis over the long term.

The role of nitrogen in apple orchards: Although previous nitrogen fertilization regimes have recommended as much as 200 kg/ha, this is now generally recognized as excessive and current standard recommendations are 60 kg/ha (Tagliavini and Marangoni, 2002). Westwood (1978) notes that excessive N can cause a reduction in fruit color and firmness as well as an overabundance of vegetative growth which, if it is late season, can leave trees vulnerable to winter injury. It should be noted that rootstock cultivar can influence efficiency of nutrient uptake (Awad and Kenworthy, 1963).

Uptake of N by apple trees - form of uptake and seasonality: The timing of nitrogen application is important whether using cover crops, synthetic fertilizer, or other nutrient options. Apple trees first make use of stored N in the spring as growth commences (Tagliavini et al., 2005; Sanchez et al., 1990) so the application of fertilizers too early in the spring may result in less uptake and more leaching. Using ^{15}N-labeled fertilizer, Guak et al., (2003) found that commencement of uptake did not begin until 14 days after remobilization of stored N had started. This is supported by Dong et al., (2001) who found that most N remobilization occurs before root uptake begins. Amino acids in the xylem may inhibit root uptake of N during remobilization, and root uptake of N is responsible for the remainder of N uptake in the growing season, but not very early growth (Tagliavini and Millard, 2005). Using ^{15}N to examine seasonality and uptake efficiency of various apple rootstocks, root uptake generally commenced after bloom, and spring uptake in general was higher and more efficient than uptake of fall-applied nitrogen (Aguirre et al., 2001). Tracking nitrogen use in Gala apple trees, Cheng and Raba (2009) found that greatest use of current season nitrogen (and most rapid uptake) occurred between bloom and the end of shoot growth, and that ultimately current season uptake and use of remobilized stored nitrogen each accounted for 50% of the total nitrogen found in tree tissues in destructive sampling at harvest time. The importance of internally remobilized N appears to increase with tree age, leading to less reliance in mature trees on early spring-applied fertilizers (Khemira et al., 1998).

Seasonal accumulation of nitrogen in foliage**:** Apple trees take up nitrogen through their root systems beginning at late bloom in the spring and continuing into fall. Investigating pears rather than apples, Sanchez et al. (1990) found that presence of ^{15}N labeled from fertilizers applied four weeks prior to full bloom was significant in developing tissues (leaves and shoots) two weeks after full bloom. Late in the growing season, trees will reallocate N from leaves to perennial tissues prior to abscission, and store it for winter dormancy and spring bud break. In another *Rosaceae* fruit crop, peaches, 35-70% of leaf N is relocated from leaves to winter storage tissue (Munoz et al., 1993). Additionally, the period of highest N root uptake occurred during periods of fruit ripening as well as maximal vegetative growth (Munoz et al., 1993). Assuming that foliar nutrient content is a reasonable reflection of plant nutrient uptake, Nachtigall and Dechen (2006) measured leaf nutrient levels from two weeks after bloom until four weeks after harvest on apple trees and found that N, P, K, as well as Cu and B decreased, and Ca increased, but that other nutrients such as Mg, Fe, Mn, and Zn varied little over the course of the season. N decreased steadily over the first 5 weeks after bloom in all three cultivars studied and then more gradually the rest of the season until late season when levels decreased more steeply as leaf N was reallocated to winter storage prior to abscission. Foliar N is present largely in the form of proteins, but to be translocated prior to leaf abscission in the fall, N must be converted (through hydrolysis) to amino acids and then back to proteins for storage in bark tissues (Titus, 1989). In late dormancy proteins undergo hydrolysis to be translocated for use in developing tissues as growth resumes.

<u>Problems associated with deficient or excessive nitrogen:</u> Over application of N is not uncommon in conventional management systems, and can cause a host of fruit problems ranging from premature fruit drop to a range of post-harvest and storage complications including scald, bitter pit, and internal browning (Bramlage et al., 1980). Fallahi et al. (2001) suggest that very high levels of N (549 g N/tree) resulted in difficulties with K uptake, preventing optimal growth and yield, and that very low N rates (45g N/tree) yielded smaller fruit. However, at the low rate

fruit was very firm and colored well, both characteristics which decline as N levels increase. Additionally, high levels of N can spur excessive vegetative growth, leading to greater chances of winter cold injury (Haynes, 1980) as well as affecting overall N budgets in creating more material that will be removed from the orchard through pruning. Fallahi et al. (2001) concluded that the optimal N rate for apple was 65.8 g/tree/yr.

Limited N has multiple physiological effects on apple trees. Limited N restricts CO_2 assimilation and stomatal conductance (Chen and Cheng, 2004), and lower N application rates decreases photosynthetic rate (Fallahi et al., 2001). Deficient N will also manifest in weak vegetative growth, reduced fruit set, a tendency toward biennial bearing, and increased sensitivity to bloom or fruit thinning agents (Stiles and Reid, 1991).

Relationships of vegetative root and shoot growth with nitrogen uptake and use by fruit trees: Many of the studies of the response of apple trees to vegetative competition have been conducted on young trees or newly established orchards, but Atucha et al. (2011) investigated the long-term effects of different ground cover management systems in an apple orchard over a span of 16 years and found that although there were early differences between sod, mulch, and both pre- and post-emergent herbicides, the trees adaptively compensated for the competition over time. Additionally, some researchers have concluded that the timing of creating a weed-free area may be more important than the size of the weed-free zone. Merwin and Ray (1997) showed that apple trees, particularly younger trees, responded better to early-season weed suppression. It should be noted that B.9 rootstocks used in the field portion of this study were found by Aguirre, et al. (2001) to have a reduced N uptake efficiency compared to all but one of the rootstocks analyzed for uptake capabilities.

Hypothesis and Objectives

Following are the hypotheses which framed the studies of this thesis.

It was predicted that orchard cover crops would affect soil quality and nutrient content, tree growth, and nutrition. It was the hypothesis that nitrogen that would be biologically sequestered by orchard drive-row cover crops would not be available for utilization by apple trees. Further, it was hypothesized that nutrients sequestered by orchard drive-row cover crops when moved within the tree-row as a mulch would be accessible to trees for uptake.

The objective of this thesis was to examine the use of drive row cover crops in an apple orchard as a means of providing a nutrient benefit to the trees. The premise of the study was that due to the non-competitive nature of apple tree roots and the relative lack of lateral movement of N in the soil, N-fixing cover crops grown in the drive alley do not provide apple trees with nitrogen. However, a well-managed mow/blow approach, in which N-fixing cover crops are grown in the drive row, and mown and moved onto the tree row, may provide available N delivered at times of the year when apple trees need nitrogen for root uptake. This management system could provide weed suppression as a mulch, and improve soil organic matter.

This study examined legume species seasonal rotation and cereal-grass species seasonal rotation drive-row cover crops coupled with mow/blow treatments, compared to a managed native vegetation control with the goal of determining if there is a difference in soil C and N between cover crop families and management approaches. A full year cycle of warm and cool season cover crops was assessed.

In testing these hypotheses, it was the goal of this research to study the biological accumulation, and release of nitrogen by selected orchard drive row cover crops as well as examine, in the field study, the lateral and horizontal distribution of sequestered and available nitrogen from these crops. In a greenhouse study, the effects of competition from cover crops on young apple trees was examined, as was the effect of legume and non-legume mulching treatments on the accumulation of N in apple tissues and the growth of young potted apple trees.

Cover Crop Species Used

To enable growing two cover crops per year (one spring planted and one fall planted), annual legume and grass species were chosen for study. Because most legumes contain the highest levels of nitrogen content at blossom (and before seed set), species were chosen to coincide with desired harvest times which could provide available N when fruit tree uptake is greatest. Species were selected for study that would be readily available to orchardists in this region.

Winter cycle cover crops: Crimson clover (*Trifolium incarnatum* L.*)* is a cool season annual legume which produces high biomass and relatively high rates of nitrogen fixation. The cultivar, AU Robin, exhibits early maturity and average to above average biomass production (Harrison et al., 2006). Crimson clover has maximum N accumulation at late bloom stage, and kills easily by mowing after early bud stage. However, it is not tolerant of waterlogged soils or pH extremes, and at pH 5.0 or lower will not fix N or even form nodules (Clark, 2007). Additionally, crimson clover plantings result in less weed biomass than when using perennial clovers (such as red or white) as spring cover crops (Nelson et al., 1991). Crude protein is approximately 17.7% (Duke, 1981). It is of Mediterranean and Eurosiberian centers of diversity, and tolerant of heavy soils, nematodes, and virus and weed pressure. Most older cultivars are diploid, but many newer releases are triploid and have lower cold tolerance. 'AU Robin' is diploid. Estimates of crimson clover biological nitrogen fixation vary from 100-150 kg N_2/ha (Wagger, 1989), or 124-185 kg N_2/ha (Ladha and Peoples, 1994), to 189 kg/ha, as per Evers and Parsons (2011). Odhiambo and Bomke (2000) assert that crimson clover can provide the relatively rapid release of enough nitrogen to sustain the growth of other crops.

For annual ryegrass (*Lolium perenne* L. *subsp. multiflorum* (Lam.) Husnot), tetraploid cultivars have less cold tolerance than diploid varieties, and for this study the common cultivar Gulf was chosen for cold hardiness, rust resistance, and availability. Annual rye is one of the best cover crops for weed suppression (Nelson et al., 1991). Rye residues can suppress weed growth for up to 6 weeks after plant desiccation (Putnam et al., (1983), and in the SARE handbook *Managing Cover Crops Profitably*, Clark (2007) recommends the crop for controlling erosion, building soil structure, weed suppression, and as a nutrient catch crop.

<u>Summer cycle cover crops:</u> Cowpeas (*Vigna unguiculata* (L.) Walp.) have extensive root systems, giving them good drought tolerance in an unirrigated orchard drive row, and generally reach maximum biomass between 60 and 90 days. The species originates in Africa and Asia. Plants reach a maximum height of 60 cm, making them manageable in an orchard setting, and have a protein content of 23-25% (Duke, 1981). The cultivar Iron Clay was selected for this study for its resistance to root-knot nematodes and high biomass production. 'Iron Clay' is the leading cover crop cultivar among cowpeas (Harrison et al., 2006) and is resistant to southern root-knot nematodes. However, cowpeas can also be susceptible to cowpea curculio and sting nematodes. As with many broadleaf crops, cowpeas may attract undesirable stinkbug populations, but these do not usually inhabit cowpeas until fruit is maturing, and in a cover-cropping function, plants are cut to the ground prior to fruit set, thus avoiding becoming a pest attractant. Of biologically fixed nitrogen in cowpeas, 84% can be found in the above-ground

portions of the plant rather than the root system (McLeod, 1982), and they can fix up to 201 kg N/ha (Ladha and Peoples, 1994).

German foxtail millet (*Setaria italica* (L.) Beauv.) has been used as a summer annual grass cover crop - it is early maturing and relatively drought-tolerant. Abdul-Baki et al. (1997) reported nitrogen content of 10 g/kg of biomass and at a seeding rate of 40 kg/ha yielded 83 g N/ha in a study of cover crops in broccoli production in Maryland. However, in a study using millet and cowpeas for cover crops in onion production in North Carolina, Vollmer and Creamer, et al. (2010) reported a nitrogen content of 20 g N/kg and 123 kg N/ha at a seeding rate of 25 kg/ha.

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CHAPTER 2: Study 1 - A Greenhouse Study of the Effects of Cover Crops and their Residues on Apple Trees

Abstract: A controlled environment study was conducted in a greenhouse, pairing the cover crop species of the field study with young potted 'M26' apple trees (*Malus domestica*) to examine the effects of both cover crop competition and cover crop mulches on tree growth and nutrient status. Potted apples in inert media were grown with and without cover crop competition, and cover crops were cut and mulched to the media surface. Cover crops of cowpeas (*Vigna unguiculata*) and German foxtail millet (*Setaria italica*) were assessed at harvest for N and C content and total biomass. Apple tree shoot caliper, length, and estimated chlorophyll content were measured weekly. At destructive harvest, trees were separated into root, shank, shoot and leaf fractions and assessed for dry weight, N and C content, and leaf number and area. The legume cover crops generated more biomass per plant, higher % and total N, and total C. Trees grown in competition with cover crops grew less than those without and did not recover after cover crop harvest within the duration of the study. Trees grown with neither competition nor mulches had greater growth than either competition treatment.

Introduction

Cover crop use in horticultural applications has received increasing attention. Considerable research has been conducted to study the benefits of cover crops in annual cropping systems. The body of knowledge of cover crops in perennial cropping systems is less complete. A method of examining specific effects of cover crops on perennial plants is to use a controlled environment greenhouse system study, reducing external parameters and magnifying both cause and effect. In our study, apple trees were used as a model plant system grown in a greenhouse study with an inert substrate to examine the effects of cover crop competition and of decomposing cover crop residues, both grass and legume, on plant growth.

The potential benefits of cover crop use have been well-supported. Cover crops can provide weed control (Tworkoski and Glenn, 2012; Fisk et al., 2001; Barnes and Putnam, 1983), nutrient production through nitrogen-fixing legumes, nutrient scavenging, reduced fertilizer runoff and leaching, the moderation of soil moisture and temperature extremes (Atucha, et al., 2011), habitat for beneficial insects which may provide pest suppression (Snapp et al., 2005), and add organic matter for soil improvement. Using cover crops as a mulch reduces the rate of evaporation of moisture from the soil and improves soil physical and biological properties (Fageria, 2005).

Studies of cover crop use in perennial systems, particularly fruit orchards, have shown some potential difficulties with root competition between cover crops and fruit trees (Atkinson et al., 1977, Dawson et al., 2001), although negative effects appear to diminish once trees are well established (Harrington et al., 2005). These studies and others have investigated the use and effects of cover crops grown within the tree row, while others have focused on the effects of drive row cover crops on pest populations, and still others have examined different blends of cover crop species, yet few have examined the underlying assumption that fruit trees gain a nutrient benefit from cover crops planted in the orchard drive row. Our study evaluated the benefits of drive row cover crops mulched in situ (where they were grown in the drive row) versus delivered as a mulch to the tree row. Additionally, there was a comparison of legumes and annual grasses, to examine if there is a difference in soil nutrient status between a nitrogen fixing cover crop mulch and the mulch from a more traditional grass drive row planting.

Hypotheses: The first hypothesis was that grass and legume cover crops would not affect growth of young apple trees. The second hypothesis was that, when grass or legume cover crops were applied as a mulch, they would not affect the growth of young apple trees. The objectives of these experiments were to study the effects of a grass and legume when grown with a young apple tree in a split pot study, and to study the effects of applying a grass and legume cover crop as a mulch on the growth and development of young apple trees grown in inert media in controlled greenhouse conditions.

Materials and Methods

A controlled study using potted apple trees was conducted in an inflated bilayer Quonset greenhouse at the University of Arkansas System Division of Agriculture (UADOA) Research and Extension Center, Horticulture Research Station in Fayetteville, Arkansas (36.099568°N, -94.171960°W). The greenhouse has a natural gas heating unit and fan system and was cooled by a pad-and-fan system in warm weather. The study was conducted in two annual experiments, first in 2012 and repeated in 2013.

General Experimental Conditions and 2012 Procedures

Twelve-liter black plastic nursery pots were filled to within 4 cm of the top with a mix of equal parts sand, perlite, and vermiculite. An acrylic divider (approx. 0.25 cm thickness) was inserted in the center-line of the pot from 1 cm above the media surface to 14 cm below the media surface to moderate upper level root competition. On one side of each pot, a 0.625-cm standard diameter ‘M.26’ apple tree was planted. Trees were pruned to 15 cm above the media line and trained to a single shoot upon budbreak and shoot emergence. Greenhouse temperature ranges were set between 18° and 33°C. However, daily high temperatures exceeded set limits in

July and August. The house was heated with a forced air gas unit heater with circulation fans. It was cooled with a hydrated-pad and fan system. No supplemental lighting was used in 2012.

Tree Maintenance and Care

Trees were planted on 28 March 2012, and 11 March 2013. Plants were watered to saturation as needed, and provided with ¼-strength Peters® (Everris NA, Inc.) soluble 20-20-20 fertilizer (starting in late May as nutrient deficiencies became apparent). Fertilizer was applied after watering, to saturation. One soil-surface treatment of the granular systemic pesticide imidacloprid (Marathon®, OHP, Inc.) was applied at a rate of 15 mL per pot on 20 April, 2012, and another on 6 July, 2012, for control of mites (*Tetranychus urticus*) and aphids (*Myzus persicae*). Potassium salts of fatty acid insecticidal soap (M-Pede® Gowan Company) was sprayed as needed to minimize pests.

Treatments and Experimental Design

Treatments: When plant shoots reached an average length of 15 cm of new growth, treatment sets were blocked by shoot length, so that for each treatment replication, all experimental units were approximately the same length for newly emerged shoot growth. Five treatments with 11 single pot replications were established in March 2012 and repeated March 2013. The five treatments established on 27 April, 2012 (day 0) were; 1) cowpeas (*Vigna unguiculata*) grown in competition with apple trees (CP), 2) German foxtail millet (*Setaria italica*) grown in competition with apple trees (FM), 3) cowpeas grown separately and mulched to media surface of apple trees (CPM), 4) millet grown separately and mulched to media surface of apple trees (FMM), and 5) control (NT), with no cover crops or mulches. Cover crops were seeded directly into the pots and thinned to five plants per pot after seedling germination and emergence.

Additional 12-L pots of cover crops were grown (with cover crops on both sides of the pot divider) at the same density to use as mulch for CPM and FMM treatments. Once treatments were assigned all pots were randomized and placed in three sections on greenhouse benches. Pots were spaced approximately 10 cm apart.

Experimental design: This study was set up as a randomized complete block design with 11 replications. Each tree represents a single experimental unit. Data were analyzed by SAS (Cary, S.C.) software using PROC GLM for Tukey-Kramer mean separation analysis. Growth curves were created with a 4th degree ANCOVA, graphs generated using SAS/Graph, Version 9.4 for Windows. Separation of means based on numbers generated by the 4th degree ANCOVA regression were calculated at harvest date and every two weeks thereafter.

Measurement Variables

Beginning at cover crop seeding, weekly measurements were collected for apple tree shoot diameter (taken at one cm from shoot-shank junction), shoot length, and estimated chlorophyll content (SPAD®502, Spectrum Technologies, Aurora, IL), measured on the fifth open leaf from the terminal bud of each rootstock. Measurements were collected every 7 days until October 9, 2012. Gas exchange of apples trees was measured on October 9, 2012. Using a CIRAS-1® portable infrared gas analyzer (PP-Systems, Hitchens, Herts, U.K.) and a Parkinson® leaf cuvette (2.5cm^2), photosynthetic rate (Pn), leaf evapotranspiration (Et), and stomatal conductance (gs) were measured at the fifth open leaf, midway between the leaf terminal and petiole and midway between the margin and mid-vein. Measurements were conducted in the greenhouse during morning hours. Instrument leaf chamber settings included photosynthetically active radiation (PAR) in the leaf cuvette set at 1200 µmol m^{-2} s^{-1}. Air flow within the leaf cuvette was 204 ml min^{-1} using 360 ppm CO_2 and 25°C chamber temperature, with 50% relative humidity.

As the foxtail millet matured earlier than the cowpeas, cover crop destruction was conducted on two dates in July at approximately 74 and 85 days after planting, respectively. Cover crops were cut at 10 cm above soil line, weighed, and then cut into 10 -15 cm sections. A subsample of approximately 5 g was separated for use in nutrient analysis, and the remainder returned to the pot surface as mulch. These subsamples were dried for 72 hours at 60°C, weighed, and ground to pass through a 1-mm mesh screen. 10mg. samples were then analyzed for C and N content using an Elementar Vario EL Cube catalytic combustion elemental analyzer (Elementar Americas, Inc., USA). Cover crops were cut for FM and FMM 2-July and CP and CPM treatments on 20-July when cowpeas had reached bud stage. Plants were cut from the extra cover crops to mulch the CPM and FMM treatments. An additional three whole millet and cowpea plants were cut, weighed, and dried, then ground for further analysis. Tissue N and C content was measured and described as percentage of dry matter.

On 9-October, 2012, all apple leaves were separated from shoots by hand and counted before measuring total leaf area (cm^2) with a LiCorLI-3000-A Portable Leaf Area Meter. Plants were then removed from pots, washed to remove media from roots, and divided with hand pruners into shoot, shank, and root fractions. Leaf, root, shoot, and shank fractions were dried for 72 hours at 60°C, weighed, ground to pass through a 1-mm mesh screen, and analyzed for total %C and %N as described previously using 10 mg samples for leaf fractions and 20 mg samples for root, shoot, and shank fractions using the Elementar Vario EL Cube. The larger sample for root, shoot, and shank was used due to lower detection of %N content in those plant fractions.

2013 Experimental Procedures:

The experiment was repeated in 2013 to verify previous season results. Trees were planted 11-March, 2013, and three high intensity discharge (HID) lights were installed 1.5-m above greenhouse bench height to extend day length to 16 hours by running 4-8 am from 1-April to 24-May. Pots were placed on greenhouse benches reinforced with expanded steel mesh to improve pot drainage and reduce cover crop root growth outside of pots.

Dilute Peters® (Everris NA, Inc.) 20-20-20 was added with watering to trees weekly starting 26-April, and imidacloprid granular insecticide (Marathon ®, OHP, Inc.) was applied twice, on 19-April and 14-June. Spider mites (*Tetranychus urtica)* were observed on cowpeas by 15-June, which affected plant quality. Mites spread to apple trees, where foliar damage was sustained prior to control with M-Pede® (Gowan Company) insecticidal soap. Cover crops were harvested on 2-July.

All cover crops for CP and FM treatments were cut at soil line to reduce regrowth which was observed in 2012. Plants were weighed, subsampled for analysis, cut into 10-15 cm sections, and mulched back to their original pots. CPM and FMM received cover crop mulches from plants grown in separate pots.

Weekly apple tree measurements continued for 48 days after cover crop harvest and then apple tree destructive harvest was carried out on 22-August, 2013, following the same protocols as the previous year. Composite media samples were taken from each treatment at harvest date and saturation extract analysis was conducted for pH, EC, and micro and macro nutrients. Gas exchange measurements were taken 21-August.

Results

Treatment Effects on Cover Crops: Above-ground, harvested portions only of cover crop tissue was assessed for N, and legumes had over three times the %N of millet. Cover crop tissue analysis (Table 2.1, 2.2) indicated differences between species in both years. Cowpea contained over four times higher % N than millet in 2012 and 2013. Cowpea grown with apple trees, while having statistically similar N concentration to cowpea grown with other cowpea, had greater total N. For 2012 and 2013 cowpea grown with trees had the highest total N and total C of all treatments. 2013 millet had greater dry weight grown with a tree than millet grown with millet. In 2012, % C was lower for millet grown with apple trees than for other treatments, but all treatments were statistically similar in 2013. Total C was greatest for both cowpea treatments in 2012, and in 2013 cowpea grown with apple trees had the greatest total C.

Treatment Effects on Apple Trees

Shoot growth: Shoot growth patterns were analyzed by fourth degree ANCOVA regression. During 2012 (Figure 2.1), trees in the CP treatment had the least amount of growth over the course of the season. Using separations generated by the ANCOVA analysis (Table 2.3), comparisons starting at cover crop harvest (79 days), show both CPM and FMM (which at that point had received no mulch effect) had significantly greater shoot growth. At 93 days this remained true, with NT also statistically similar to CPM, while the average shoot length for CP (cowpea competition) was the least of all treatments. At 107 days FMM had the greatest shoot growth of all treatments. This remained true at 121 days and 135 days. At harvest date, 161 days, analyzed both through 4^{th} degree regression and simple mean separations (Table 2.4), both treatments with cover crop competition (CP and FM) had less shoot growth than any treatment without competition, including the control.

In 2013 (Figure 2.2), the growth patterns were different, with more separation between treatments. Both competition treatments lagged behind other treatments in shoot growth, but had a marked upswing in growth curves late in the season. Analyses every 14 days from cover crop harvest onward based on numbers generated by the ANCOVA regression showed few statistical differences between treatments (Table 2.5). However, average size at final confirmed the pattern of greater shoot growth for all treatments without cover crop competition (Table 2.6).

Shoot Diameter: In 2012 a 4^{th} degree ANCOVA analysis of shoot diameter measurements (Figure 2.3) conducted over the course of the season showed separations between competition treatments and all other treatments by the cover crop harvest date, which became more pronounced as the season progressed (Table 2.7). Both CPM and FMM had greater shoot diameter than other treatments throughout the analysis period. By the end of the season, CP had the least total increase in shoot diameter, and FMM, CPM, and NT had the greatest gain (Table 2.8).

Shoot diameter in 2013 (Figure 2.4) was analyzed by 4^{th} degree ANCOVA and evidenced increasing differences between competition treatments and those without cover crop competition with increasing time from cover crop harvest. Mean separations of tree height based on the regression analysis showed that CPM and FMM treated trees had the largest diameter at all measurement dates (Table 2.9). Simple mean separations of end-of-season data assessed CPM, FMM, and NT all statistically similarly, and CP and FM had trees with significantly smaller diameter shoot measurements (Table 2.10).

Estimated Chlorophyll: Estimated chlorophyll, measured by SPAD metering, was analyzed with 4^{th} degree regression ANCOVA in 2012 (Figure 2.5), and linear ANCOVA in 2013 (Figure 2.6). In 2012, although FMM and NT tended to have higher SPAD readings during the season, there were no statistical separations by the end of the measurement period (Tables 2.11, 2.12). In 2013, FM consistently had the lowest SPAD estimated chlorophyll at all analysis dates, and at the end of the season, CPM, FMM, and NT were statistically similar (Tables 2.13, 2.14).

Tissue Carbon and Nitrogen Contents: Apple Tree Fraction Tissue Analysis: 2012 analysis had minor differences (Table 2.15), including root %N, with CP having the highest percentage, statistically similar to CPM, which was similar to all other treatments. In 2013 (Table 2.16), shoot %N was higher for both legume treatments (CP and CPM) than for the control. The 2012 leaf analysis (Table 2.17) indicated no significant differences among treatments. In 2013 (Table 2.18), CPM had the greatest total N, and the mulching treatments (CPM and FMM) also had greatest total C. FMM had the lowest total N and total C .

Tree biomass: In 2012, sample variability translated too few significant differences between treatments (Table 2.19). In 2013 (Table 2.20) competition treatments showed significant effects, with lower root weight than mulching or control treatments. Because of having less vegetative growth, shank weight as a percentage of total weight was highest for CP and FM, and shoot weight as a percentage of total weight was lowest. The cowpea mulch treatment, CPM, had the greatest shoot weight, followed by FMM, then NT.

Tree Foliage Development: Due to variability of the sample, significant differences were limited in the 2012 experiment (Table 2.21). In 2013 (Table 2.22), leaf weight was greatest for CPM, and least for both mulching treatments. The competition treatments had less leaf number, smaller leaf area, and less total dry weight than all other treatments.

Tree Foliage Gas Exchange: Gas analysis results (Table 2.23) are reported for October, 2012 only. Intercellular CO_2 concentration (C_i) was similar for all treatments except NT, which was significantly lower. Net photosynthetic rate (A) was statistically similar for all non-competition treatments and NT was higher than both competition treatments (CP and FM). Stomatal conductance (gs) and evapotranspiration (Et) were statistically similar among all treatments.

Treatment Effects on Media: Analysis of potting media at the end of the 2013 study, while not large enough for statistical sampling, showed greater N in the media of the CP treatment, where nodulated cowpea roots were decomposing. Potassium, calcium, sulfur, EC were also notably higher in this treatment. Media nitrogen levels were higher for both cowpea treatments than all other treatments, pointing to greater nitrogen availability when using legume cover crops as a potential nitrogen source. Media effluent pH was highest in NT and both millet treatments, ranging from 7.0 for FM to 7.6 for NT (Appendix A.1). Media effluent from both cowpea treatments had lower pH- 6.5 for CP and 6.8 for CPM.

Discussion

The inhibitory effect of cover crop competition on apple trees is supported by previous studies. Merwin and Stiles (1994), using crown vetch and both mowed and growth-regulated sod as grass and legume treatments, found that these lagged behind all other understory management treatments (tillage and herbicide) in trunk cross sectional area (TCSA). Atkinson et al. (1977) and Hogue and Neilsen (1987) additionally supported findings of inhibitory effects of ground covers on apple tree growth.

Cowpea produced more than three times the above-ground biomass of foxtail millet in the potted, controlled environment, generating a thicker, more solid layer of mulch in the pots of apple trees, but also creating greater competition (prior to harvest) than millet for the young apple trees in the competition treatments. Gregory (2006), in his book Plant Roots, synthesizes studies by Gregory and Squire (1979) and Devi et al. (1996) to demonstrate differences in root mass between pigeon peas and pearl millet, and although root mass was not measured for cover crops in our study, it was observed in that the cowpea root systems appeared to be of greater bulk and length than the millet. Root growth through drainage holes beyond the constraints of the pot was also observed for cowpeas in 2012. Additionally, although water stress was not measured, it was observed in both cover crops and apple trees, and more obviously so in cowpea competition treatments.

Cowpea N content averaged around 2.3%, which is slightly lower than findings in a protected environment, neutral-media study conducted by Herridge and Pate (1977) of 2.5-3.1% for the vegetative growth phase. In a study of respiratory losses, maximal CO_2 losses from nodule respiration occurred at 60-70 days of growth (Herridge and Pate, 1977). This respiratory rate would correspond to large O_2 use, producing a potentially anaerobic root zone environment for the trees grown with cowpea competition. Root respiration of a legume (pigeon peas) was 188% higher than that of a cereal (maize), and 121% higher than another cereal (sorghum) (Rao and Ito, 1998). Additionally, root respiration rate was correlated with nitrogen uptake, with both being significantly greater in legumes than grasses (Rao and Ito, 1998). Thus, it appears that both competition and specifically competition with legume cover crops may reduce tree growth due to root zone limitations.

Overall effects on apple tree growth variables measured during the study did not show large differences between cowpea mulch and millet mulch, nor, generally, between mulch treatments and control. However, in 2013, the visual differences in growth habit by treatment were notable:the cowpea mulch treatment produced trees with long shoots that appeared to grow faster than they lignified, resulting in bending, curving shoots with large, bright green leaves (Appendix A.3), consistent with symptoms of excess N (Shear and Faust, 1980), although tissue analysis did not show excessive N content.

The majority of studies examining effects of cover crop competition on apple trees have been conducted in the field, and this controlled environment study corroborates existing field studies of young apple trees and competition. Atucha et al. (2011) have shown that effects are reduced as trees mature, but in high-density production systems, trees come into production by year 2 or 3 (Robinson et al., 2013), long before the age at which they may be less affected by cover crops in competition.

The benefits of mulches on apple trees have been documented in a number of ways. Forge et al. (2013) confirmed significant positive effects of alfalfa mulch on apple tree growth and yield, confirming improvements in 'Spartan' apples from alfalfa mulches, as well as improved tree uptake of N, P, and K from the use of alfalfa mulch (Neilsen et al., 2003). Yao et al. (2005) found that soil cation exchange capacity, soil organic matter, and pH were all greater in apple orchards under mulches when compared to other ground cover management systems, and also that soil phosphorus and carbon were increased with mulches. Surface mulches, even though never mechanically incorporated into the soil, doubled soil organic matter levels over the 12 years of the study (Yao et al., 2005). Tree growth rates increased for all mulched treatments for both years of this study as the mulches decomposed, including those trees whose growth was delayed or retarded by cover crop competition earlier in the season.

As per our objectives, we were able to study the effects of cover crop competition and cover crop mulches in a controlled environment over two summers. Our study indicated the null hypothesis likely to be untrue- in this study, cover crops, both as competition and as mulches, did affect apple tree growth. Decomposing legume cover crops resulted in apple trees within sufficiency ranges for foliar N content. However, given the adverse effects of competition, this study also demonstrated that even the control treatment grew significantly better, with no mulches and minimal fertilization, than competition treatments, even well after the cover crops were cut and the competition minimized.

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Table 2.1. Plant dry weight and plant nutrient content (above-ground fraction) of four cover crops after 73 days growth (millet) and 84 days growth (cowpeas) grown in 12-liter containers in a greenhouse in Fayetteville, Arkansas, 2012.

Treatment	% N	%C	Dry Weight (g)	Total N (g)	Total C (g)
Cowpea w/tree	2.5a[z]	41.8a	95.1a	2.4a	39.8a
Millet w/tree	0.8b	41.4b	28.9c	0.2c	11.9c
Cowpea w/cowpea	2.2a	42.0a	68.0b	1.5b	25.6b
Millet w/millet	0.5b	42.1a	16.0c	0.1c	6.7c

[z] Mean separation within columns by Tukey-Kramer. Means within a column followed by different letters are significantly different ($p \leq 0.05$). n=11 with 5 pooled plants per sample.

Table 2.2. Plant tissue dry weight and plant nutrient content (above-ground fraction) of four cover crops after 74 days growth in 12-liter containers in a greenhouse in Fayetteville, Arkansas, 2013.

Treatment	% N	%C	Dry Weight (g)	Total N (g)	Total C (g)
cowpea w/tree	3.4a[z]	42.1	43.6a	1.5a	19.2a
millet w/tree	0.7b	41.9	33.5b	0.3c	14.9b
cowpea w/cowpea	3.6a	42.2	31.3b	1.2b	14.2b
millet w/millet	0.7b	42.1	23.8c	0.2c	10.0c

[z] Mean separation within columns by Tukey-Kramer. Means followed by different letters are significantly different ($p \leq 0.05$). n=11 with 5 pooled plants per sample.

Table 2.3. The effects of five cover crop treatments on the shoot length growth of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR, 2012. Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

	Calculated mean shoot length [z] (cm)					
Treatment	79 days growth	93 days growth	107 days Growth	121 days growth	135 days growth	161 days growth
CP	21.6c[y]	22.4d	23.6d	25.3d	27.6d	32.3c
FM	23.2c	25.4c	28.4c	32.0c	36.2c	44.2b
CPM	35.3a	40.8ab	46.7b	52.7b	58.6b	67.2a
FMM	35.2a	42.4a	49.9a	57.2a	63.6a	70.6a
NT	33.4b	39.6b	46.5b	53.5b	60.3b	70.2a

[z] Mean separations based on numbers generated by 4th degree ANCOVA regression were calculated at harvest date and every fourteen days thereafter.

[y]Mean separation within columns by Tukey-Kramer. Means followed by different letters are significantly different ($p \leq 0.05$ unless otherwise noted). n=11

Table 2.4. The effects of five cover crop treatments on the shoot length growth (cm) of model, single shoot M.26 apple plants grown for 161 days in inert media in a greenhouse Fayetteville, AR, 2012. Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

Treatment	Mean shoot length (cm)
CP	32.3b[z]
FM	42.3b
CPM	68.9a
FMM	69.8a
NT	70.1a

[z]Mean separations by Tukey-Kramer. Means followed by different letters are significantly different ($p \leq 0.05$). n=11

Table 2.5. The effects of five cover crop treatments on the shoot length growth of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR, 2013. Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

	Calculated mean shoot length[z] (cm)			
Treatment	72 days growth	88 days growth	102 days growth	116 days growth
CP	34.9[y]	35.8	39.1b	48.6
FM	42.2	43.3	45.5b	52.9
CPM	65.1	79.5	92.2a	100.6
FMM	58.2	68.7	78.5ab	87.0
NT	56.7	65.1	72.1ab	78.2
	ns	ns		ns

[z]Mean separations based on numbers generated by 4th degree ANCOVA regression were calculated at cover crop harvest date and every fourteen days thereafter.

[y] Mean separation within columns by Tukey-Kramer. Means followed by different letters are significantly different ($p \leq 0.05$). ns=no significant difference among means. n=11

Table 2.6. The effects of five cover crop treatments on the shoot length growth of model, single shoot M.26 apple plants grown for 116 days in inert media in a greenhouse Fayetteville, AR, 2013. Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

Treatment	Shoot length (cm)
CP	52.0c[z]
FM	55.7c
CPM	101.5a
FMM	88.9ab
NT	79.8b

[z]Mean separation within columns by Tukey-Kramer. Means followed by different letters are significantly different (p≤0.05). n=11

Table 2.7. The effects of five cover crop treatments on the shoot diameter growth of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR, 2012. Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

	Calculated mean shoot diameter[z] (mm)					
Treatment	79 days growth	93 days of growth	107 days growth	121 days growth	135 days growth	161 days growth
CP	4.34d[y]	4.49e	4.65e	4.84e	5.07e	5.71d
FM	4.67c	4.92d	5.19d	5.5d	5.88d	6.82c
CPM	5.63a	6.18b	6.72b	7.25b	7.74b	8.57a
FMM	5.78a	6.4a	6.99a	7.56a	8.06a	8.8a
NT	5.13b	5.66c	6.17c	6.67c	7.14c	7.91b

[z]Mean separations based on numbers generated by 3rd degree ANCOVA regression were calculated at cover crop harvest date and every fourteen days thereafter.

[y]Mean separation within columns by Tukey-Kramer. Means followed by different letters are significantly different (p≤0.05). n=11

Table 2.8. The effects of five cover crop treatments on the shoot diameter of model, single shoot M.26 apple plants grown for 161 days in inert media in a greenhouse Fayetteville, AR, 2012. Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

Treatment	Shoot Diameter (mm)
CP	5.6c [z]
FM	6.6bc
CPM	8.4a
FMM	8.7a
NT	8.0ab

[z] Mean separation within columns by Tukey-Kramer. Means followed by different letters are significantly different ($p \leq 0.05$ unless otherwise noted). n=11

Table 2.9. The effects of five cover crop treatments on the shoot diameter growth of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR, 2013. Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

Calculated mean shoot diameter [z] (mm)

Treatment	72 Days	88 Days	102 Days	116 Days
CP	5.5d[y]	5.5d	5.7d	6.4d
FM	6.2c	6.3c	6.5c	7.0c
CPM	7.3a	8.0a	8.6a	9.2a
FMM	7.4a	8.1a	8.6a	9.1a
NT	7.0b	7.7b	8.3b	8.5b

[z]Mean separations based on numbers generated by 4th degree ANCOVA regression were calculated at cover crop harvest date and every fourteen days thereafter.

[y]Mean separation within columns by Tukey-Kramer.Means followed by different letters are significantly different ($p \leq 0.05$). n=11

Table 2.10. The effects of five cover crop treatments on the shoot diameter growth (mm) of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR, 2013. Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

Treatment	Shoot Diameter (mm)
CP	6.64b[z]
FM	7.27b
CPM	8.35a
FMM	9.22a
NT	8.56a

[z]Mean separation within columns by Tukey-Kramer. Means followed by different letters are significantly different (p≤0.05). n=11

Table 2.11. The effects of five cover crop treatments on estimated chlorophyll (based on SPAD metering) of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR, 2012. Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

	Calculated Chlorophyll Content[z] (SPAD units)					
Treatment	79 Days of growth	93 Days of growth	107 Days of growth	121 Days of growth	135 Days of growth	161 Days Of growth
CP	24.4c[y]	25.4d	26.5c	27.6d	29.2d	34.6
FM	27.8b	29.0c	30.1b	31.4bc	32.9bc	37.9
CPM	30.4a	30.5c	30.5b	30.5c	31.0cd	35.2
FMM	30.3a	31.4a	32.3ab	33.2ab	34.5ab	39.1
NT	31.4a	32.8a	33.9a	34.8a	35.7a	39.2
						ns

[z]Mean separations based on numbers generated by 4th degree ANCOVA regression were calculated at cover crop harvest date and every fourteen days thereafter.

[y]Mean separation within columns by Tukey-Kramer.Means followed by different letters are significantly different (p≤0.05). ns= no significant differences among means. n=11

Table 2.12. The effects of five cover crop treatments on estimated chlorophyll (based on SPAD metering) of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR, 2012 based on end of season measurements (9-Oct.). Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

Treatment	Estimated cholorophyll by SPAD meter
CP	34.6ab [z]
FM	37.0ab
CPM	34.0b
FMM	39.1ab
NT	39.5a

[z] Mean separation within columns by Tukey-Kramer. Means followed by different letters are significantly different ($p \leq 0.05$). n=11

Table 2.13.The effects of five cover crop treatments on estimated chlorophyll (based on SPAD metering) of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR, 2013. Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

	Calculated Chlorophyll Content[z] (SPAD units)			
Treatment	72 Days of growth	88 Days of growth	102 Days of growth	116 Days of growth
CP	28.88b[y]	28.46b	28.05b	27.63b
FM	25.35c	23.81c	22.27c	20.73c
CPM	29.03b	29.01b	28.98ab	28.96ab
FMM	31.04a	31.32a	31.61a	31.9a
NT	31.09a	31.38a	31.66a	31.95a

[z]Mean separations based on numbers generated by linear ANCOVA regression were calculated at cover crop harvest date and every fourteen days thereafter.

[y]Mean separation within columns by Tukey-Kramer. Means followed by different letters are significantly different ($p \leq 0.05$). n=11

Table 2.14. The effects of five cover crop treatments on estimated chlorophyll (based on SPAD metering) of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR, 2013. Measurements taken 22-Aug.Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

Treatment	Estimated Chlorophyl by SPAD meter
CP	26.9b[z]
FM	19.8c
CPM	34.8a
FMM	34.4a
NT	33.7a

[z] Mean separation within columns by Tukey-Kramer. Means followed by different letters are significantly different (p≤0.05). n=11

Table 2.15. Effects cover crops and cover crop mulches on carbon and nitrogen content of root, shank, and shoot fractions of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR. 2012. Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

	Root N (%)	Root C (%)	Shank N (%)	Shank C (%)	Shoot N (%)	Shoot C (%)
CP	1.6a[z]	40.7b	0.9a	45.3	1.1	45.8a
FM	1.1b	43.1ab	0.6ab	45.1	0.8	45.7b
CPM	1.4ab	43.8a	0.8ab	45.2	1.0	45.3c
FMM	1.1b	45.4a	0.6ab	45.0	0.7	45.4bc
NT	1.2b	44.6a	0.5b	45.0	0.6	45.3c
				ns	ns	

[z] Mean separation within columns by Tukey-Kramer. Means followed by different letters are significantly different (p≤0.05). ns= no significant differences among means. n=11

Table 2.16. Effects cover crops and cover crop mulches on carbon and nitrogen content of root, shank, and shoot fractions of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR. 2013. Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

	Root N (%)	Root C (%)	Shank N (%)	Shank C (%)	Shoot N (%)	Shoot C (%)
CP	1.4a ^{z}	39.6b	0.6	45.4	0.8a	45.6
FM	1.1b	42.8a	0.6	44.9	0.7ab	45.4
CPM	1.1bc	38.3b	0.6	44.9	0.8a	45.0
FMM	1.0c	40.2ab	0.5	45.0	0.7ab	44.8
NT	1.1bc	40.9ab	0.4	44.9	0.6b	45.2
			ns	ns		ns

^{z} Differences within columns are significant based on paired t-test at p≤0.05. ns= no significant differences among means. n=11

Table 2.17. Effects cover crops and cover crop mulches on carbon and nitrogen content of leaf fraction and total carbon and nitrogen content of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR. 2012.Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

Treatments	Leaf N (%)	Leaf C (%)	Total N (g.)	Total C (g.)
CP	1.9 ^{z}	47.8	0.3	11.5
FM	1.6	48.1	0.2	12.8
CPM	2.0	47.9	0.5	20.1
FMM	1.6	47.7	0.4	23.5
NT	1.6	47.7	0.4	20.7
	ns	ns	ns	ns

^{z}Differences between means within columns are significant based on paired t-test at p≤0.05. ns= no significant differences among means. n=11

Table 2.18. Effects cover crops and cover crop mulches on carbon and nitrogen content of leaf fraction and total carbon and nitrogen content of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR. 2013.Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

Treatments	Leaf N (%)	Leaf C (%)	Total N (g.)	Total C (g.)
CP	2.4a [z]	47.3	0.4cd	17.1c
FM	1.8bc	47.2	0.3d	17.8c
CPM	2.0b	47.4	0.7a	29.5a
FMM	1.8bc	47.3	0.5b	27.3a
NT	1.7c	47.3	0.4bc	24.3b
		ns		

[z]Differences between means within columns are significant based on paired t-test at $p \leq 0.05$. ns= no significant differences among means. n=11

Table 2.19. Effects of cover crops on dry weight of root, shoot and shank fractions of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR. 2012.Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

Treatment	Root Wt. (g.)	Root % of total wt.	Shank Wt. (g.)	Shank % of total wt.	Shoot Wt. (g.)	Shoot % of total wt.
CP	2.1[z]	9.6	14.3	68.5a	2.4	9.7a
FM	3.6	12.0	15.6	59.2ab	3.9	12.7ab
CPM	4.9	10.1	18.4	49.6ab	10.2	19.6a
FMM	7.5	14.0	21.1	45.6b	11.4	19.9a
NT	7.5	15.2	18.1	44.4b	9.3	19.2a
	ns	ns	ns		ns	

[z]Differences between means within columns are significant based on paired t-test at $p \leq 0.05$. ns= no significant differences among means. n=11

Table 2.20. Effects of cover crops on dry weight of root, shoot and shank fractions of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR. 2013.Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

Treatment	Root Wt. (g.)	Root % of total wt.	Shank Wt. (g.)	Shank % of total wt.	Shoot Wt. (g.)	Shoot % of total wt.
CP	2.7c[z]	6.8	24.4	66.5a	4.6d	11.3c
FM	2.6c	6.6	26.1	66.8a	4.7d	11.6c
CPM	5.6ab	8.2	27.8	42.3c	15.2a	23.1a
FMM	5.9a	9.4	29.6	49.0b	11.7b	19.1b
NT	4.3b	7.9	27.0	50.3b	9.9c	18.1b
		ns	ns			

[z]Differences between means within columns are significant based on paired t-test at $p \leq 0.05$. ns= no significant differences among means. n=11

Table 2.21. Effects of cover crops on leaf weight, number, and area and total dry weight of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR. 2012.Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

Treatment	Leaf wt. (g.)	Leaf % of total wt.	Total Dry wt. (g.)	Leaf No.	Leaf Area (cm^2)
CP	3.0[z]	12.1b	21.8	25.0b	344.2
FM	5.1	16.0ab	28.1	30.5ab	550.7
CPM	10.5	20.7a	43.9	50.0a	1073.5
FMM	11.3	20.5ab	51.4	47.8a	1191.1
NT	10.3	21.2a	45.2	45.5ab	1071.2
	ns		ns		ns

[z]Differences between means in columns are significant based on paired t-test at $p \leq 0.05$. ns= no significant differences among means. n=11

Table 2.22. Effects of cover crops on leaf weight, number, and area and total dry weight of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR. 2013.Treatments:CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

Treatment	Leaf wt. (g.)	Leaf % of total wt.	Total Dry wt. (g.)	Leaf No.	Leaf Area (cm^2)
CP	6.1c[z]	15.4b	37.7c	41.3d	770.2c
FM	6.1c	15.0b	39.5c	43.9cd	755.2c
CPM	17.3a	26.5a	65.9a	79.4a	1861.9a
FMM	13.6b	22.6a	60.7a	62.2b	1330.4b
NT	12.7b	23.6a	53.9b	57.0bc	1333.6b

[z]Differences between means in columns are significant based on paired t-test at $p \leq 0.05$. n=11

Table 2.23. Foliage gas exchange analysis of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR, October 2012.Ci= Intercellular CO_2 concentration, A= net photosynthesis, gs=stomatal conductance, and Et=evapotranspiration.

Treatment	Ci	A	Gs	Et
CP	291.7a[z]	7.8b	711.3	5.3
FM	286.2a	8.1b	616.8	5.6
CPM	279.4a	9.3ab	672.9	5.8
FMM	278.5a	9.8ab	751.5	5.8
NT	261.7b	12.2a	584.5	5.5
			ns	ns

[z] Mean separation within columns by Tukey-Kramer, SAS Corp, Cary, N.C. Means followed by different letters are significantly different ($p \leq 0.05$ unless otherwise noted). ns= no significant differences among means. n=11

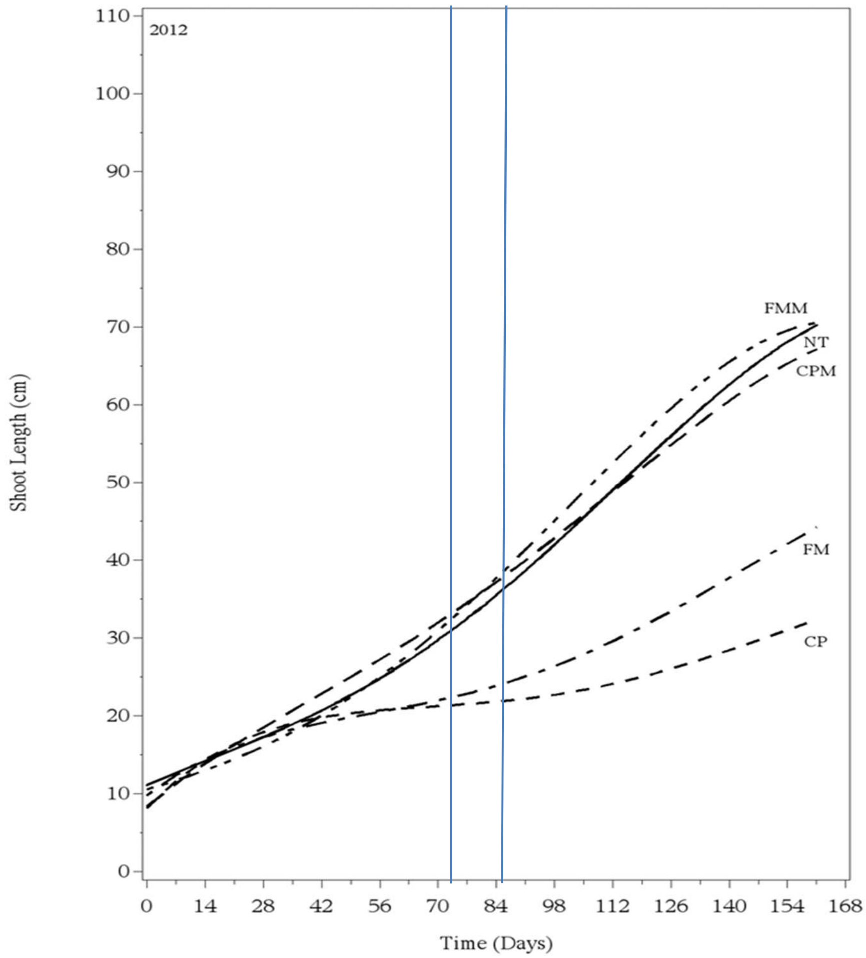

Figure 2.1. The effects of five cover crop treatments on the shoot length growth of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR, 2012. Line at 74 days= millet harvest, line at 85 days= cowpea harvest. Treatments: CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

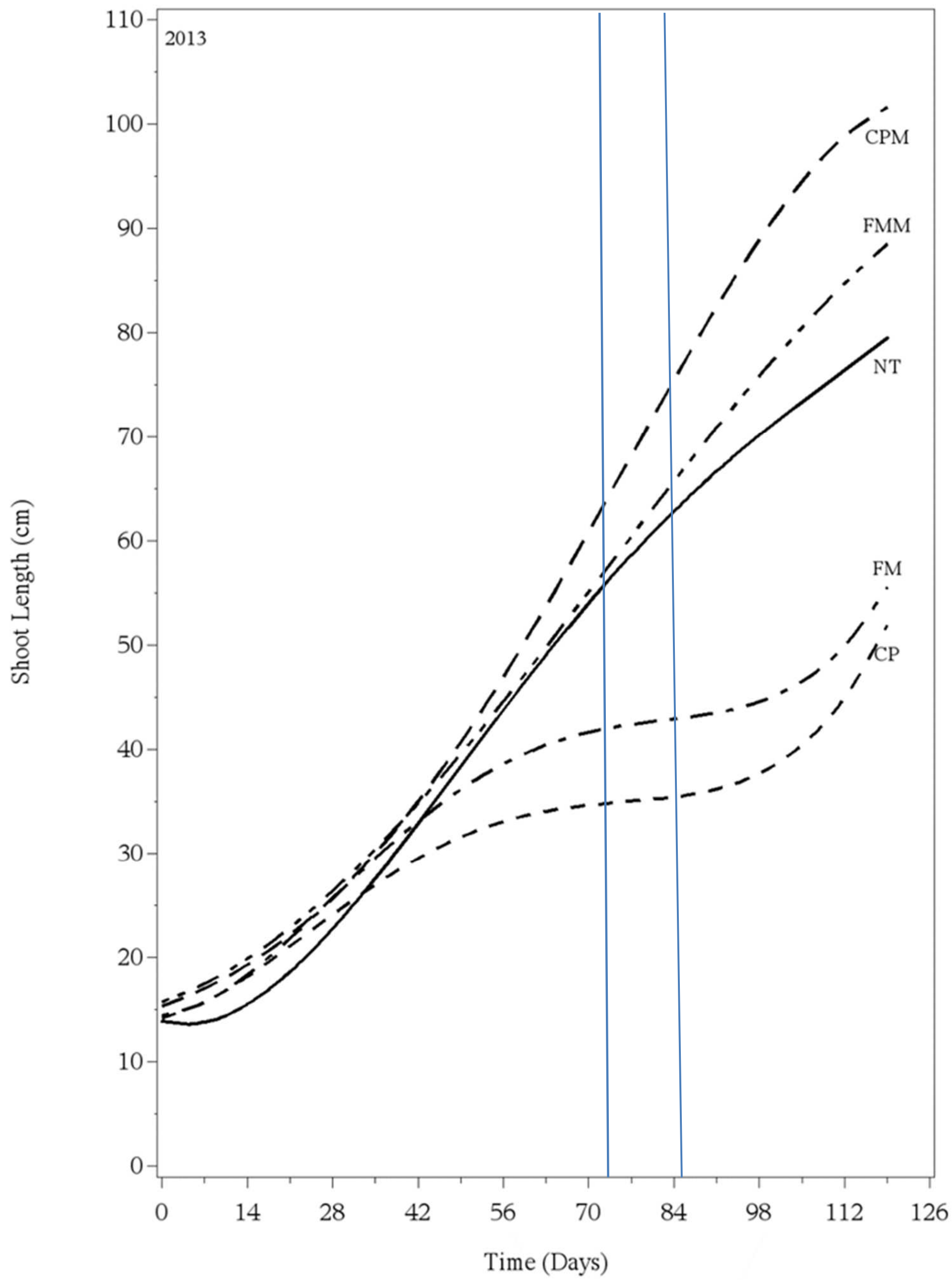

Figure 2.2. The effects of five cover crop treatments on the shoot length growth of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR, 2013. Line at 74 days= millet harvest, line at 85 days= cowpea harvest. Treatments: CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

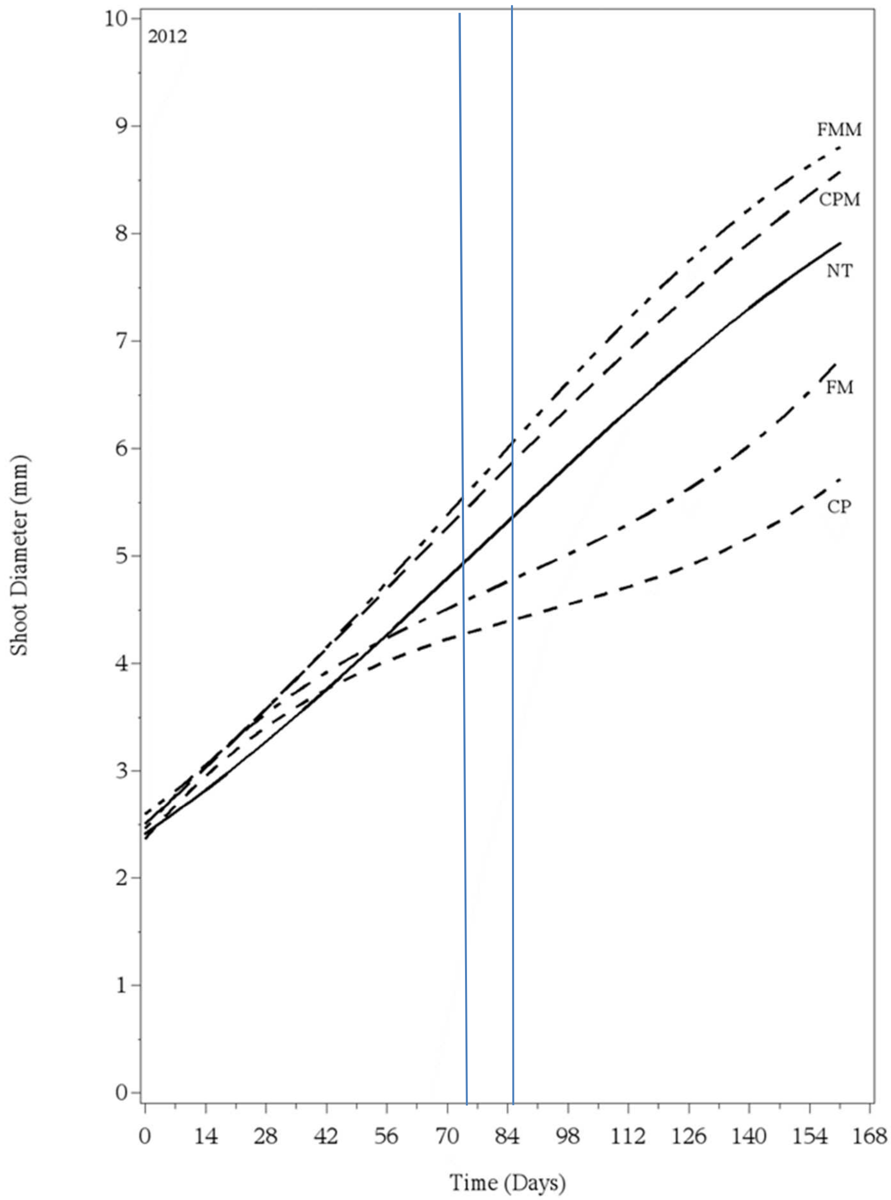

Figure 2.3. The effects of five cover crop treatments on the shoot diameter growth of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR, 2012. Line at 74 days= millet harvest, line at 85 days=cowpea harvest. Treatments: CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

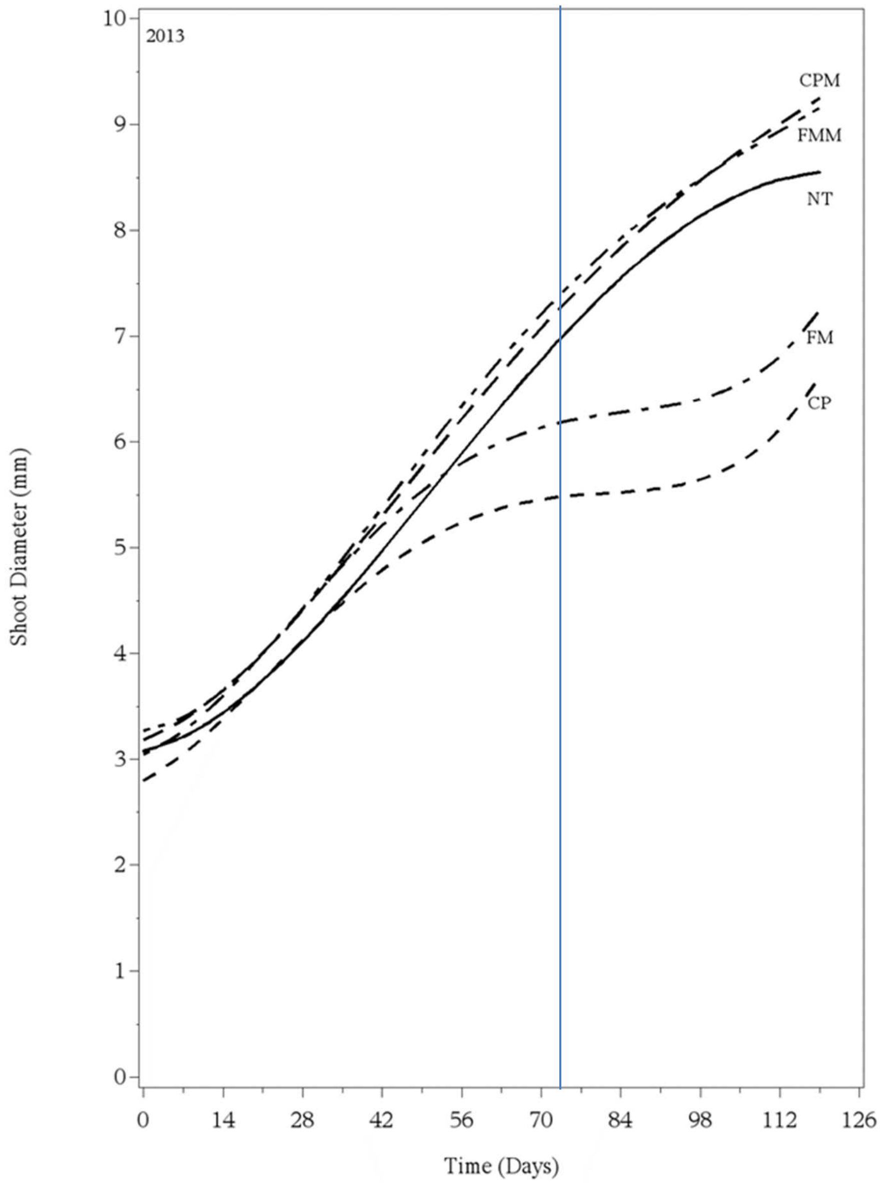

Figure 2.4. The effects of five cover crop treatments on the shoot diameter growth of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR, 2013. Line at 74 days= cover crop harvest. Treatments: CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

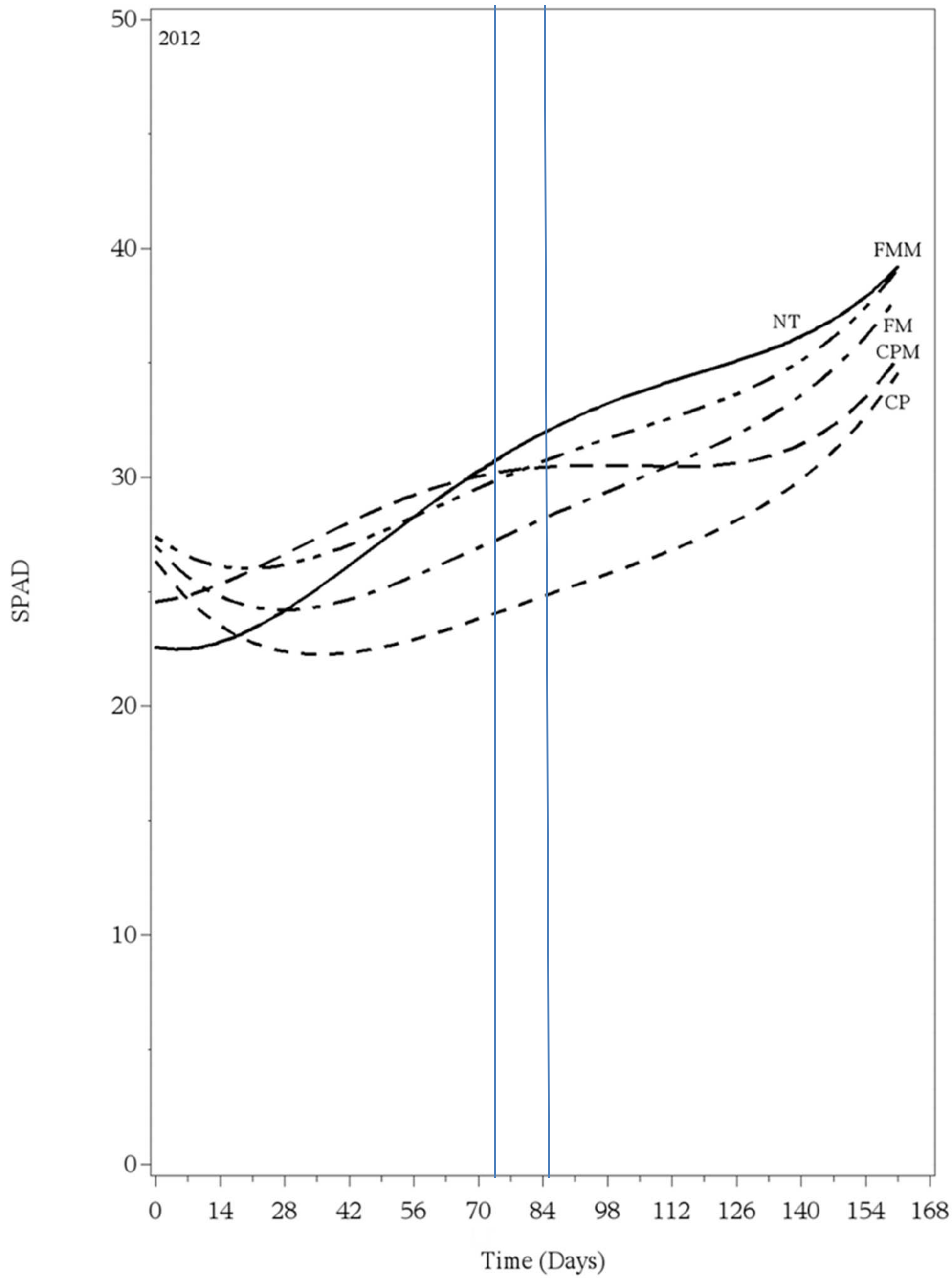

Figure 2.5. The effects of five cover crop treatments on estimated chlorophyll (based on SPAD metering) of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR, 2012.Line at 74 days= millet harvest, line at 85 days=cowpea harvest. Treatments: CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

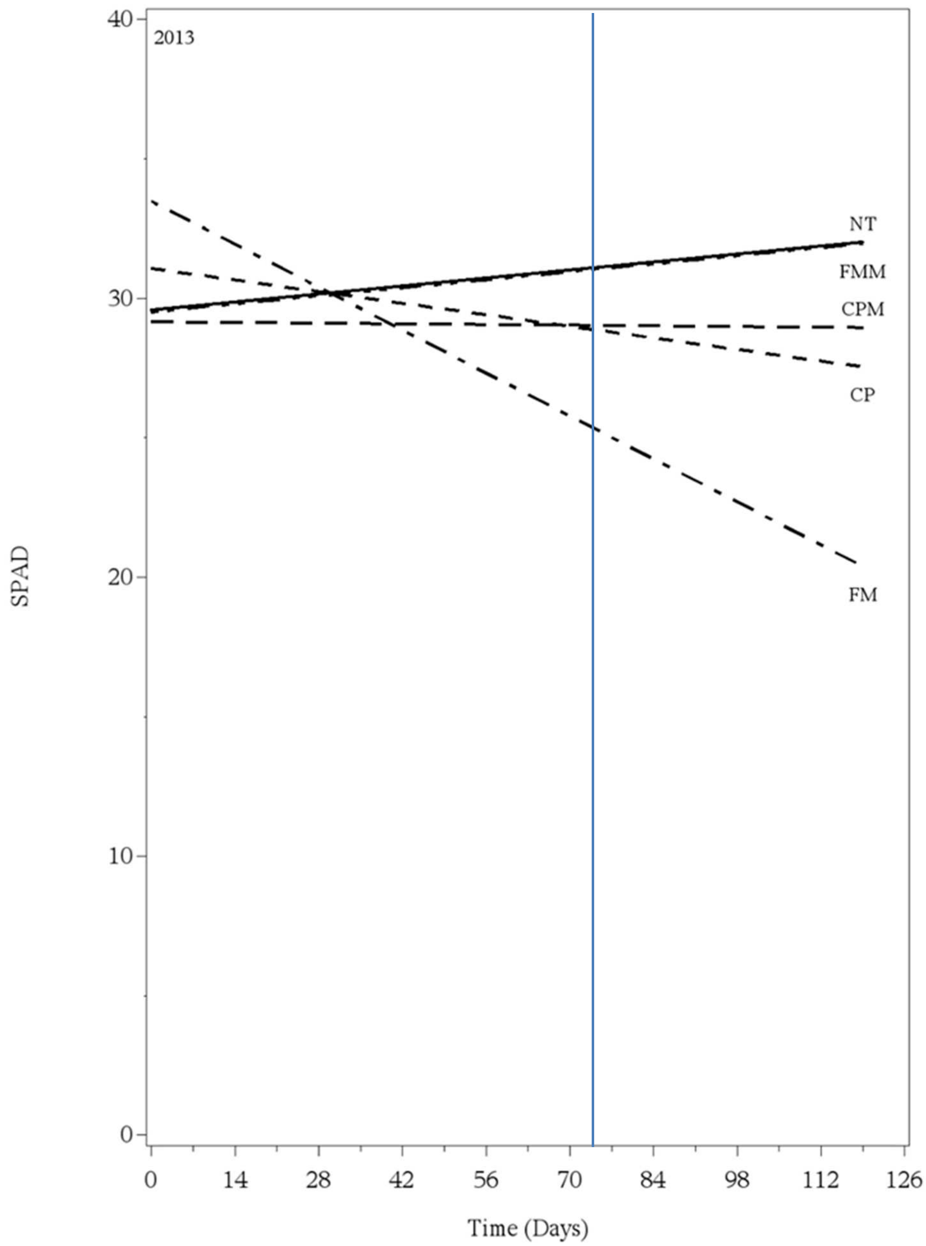

Figure 2.6. The effects of five cover crop treatments on estimated chlorophyll (based on SPAD measurement) of model, single shoot M.26 apple plants grown in inert media in a greenhouse Fayetteville, AR, 2013. Line at 74 days= cover crop harvest. Treatments: CP= Cowpea competition, FM= Foxtail millet competition, CPM=Cowpea mulch, FMM= Foxtail millet mulch, NT=no treatment/control.

CHAPTER 3: Study 2 - A Field Study of the Effects of Cover Crops on Apple Tree and Soil Nutrition during Orchard Establishment

Abstract

Ground cover management systems affect apple orchard establishment, growth and productivity as well as soil quality and health. However, there have been few studies in the southern region of the US on the effects of managed drive-rows using cover crops as part of a sustainable orchard management system. An orchard of AA184/Bud.9 apple trees was planted in 2012, Fayetteville, AR, USA. Within the orchard a study was established with treatments of 1) seasonal legumes (cowpea [*Vigna unguiculata (L.) Walp.*] in the summer and crimson clover [*Trifolium incarnatum* L.] in the winter), 2) seasonal grasses (millet **[***Setaria italica* (L.) P. Beauv.] in the summer and annual rye [*Lolium perenne* L. subsp. *multiflorum* (Lam.) Husnot**]** in the winter), and 3) a control of unmanaged natural vegetation in the drive row plantings. The legume and grass cover crops were split-plot for either A) mow-and-blow where the drive-row vegetation was moved into the tree row after mowing at the end of the cover crop growing season, or B) a control where the mowed cover crop was left in place after mowing resulting in a total of six treatments each replicated 12 times in a complete block design. Treatments were implemented for 2 years in four cycles being the summer 2012, winter 2012/2013, summer 2013, and winter of 2013/2014. The legume ground cover treatment produced more than twice as much cover crop tissue N/m² than grasses or natural vegetation treatments. Soil was sampled seasonally within both tree rows and drive alleys. Legume mulches produced the highest labile soil N compared to other ground cover management treatments, and the highest labile N where legumes were mulched to the tree-row with a mow/blow treatment. There was a lower C:N ratio for all legume treatments compared to grass or untreated control treatments, lower C:N within the tree

row compared to drive row, and highest soil N content within the tree row with legumes/ mow/blow mulch compared to all other treatments. In June, 2013, after two seasonal plantings of cover crops, labile C/N ratio was lower for legumes than grass or natural vegetation untreated control. Both the total and labile C and N pools were lower for all mow/blow treatments compared other treatments. Apple foliage sampled in August, 2013, had highest N content for the legume treatments. Shifts in soil labile N pools and tree foliar nutrient content indicate that mow/blow management of legumes in orchard systems may offer a significant N benefit to apple trees and be a potential sustainable alternative for orchard management. Long term continuation of the study will be needed to assess shifts in total C and N soil pools.

Introduction

The potential benefits of cover crop use have been well-supported in the literature. Cover crops can provide weed control (Tworkoski and Glenn, 2012; Fisk, et al., 2001; Barnes and Putnam, 1983), nutrient production through nitrogen-fixing legumes, nutrient scavenging, reduced fertilizer runoff and leaching, the moderation of soil moisture and temperature extremes (Atucha, 2011), habitat for beneficial insects which may provide pest suppression (Snapp et al., 2005), and add organic matter for soil improvement. Using cover crops as a mulch reduces the soil moisture evaporation rate, and improves soil physical and biological properties (Fageria, 2005). Studies of cover crop use in perennial systems, particularly fruit orchards, have shown some potential difficulties with root competition between cover crops and fruit trees (Atkinson et al., 1977, Dawson et al., 2001), although negative effects appear to diminish in once trees are established (Harrington et al., 2005). Some research has been conducted using cover crops within orchard tree rows for weed management and/or potential nutrient contribution (Atucha et al., 2011; Mays et al., 2014; TerAvest et al., 2010), but less exists in regards to using them as drive row plantings between tree, shrub, and vine rows (Granatstein and Sanchez, 2009).

The potential benefits of cover crop use in annual cropping systems have been supported by numerous studies (Bullock et al., 2002; Colla, 2000; Fisk et al, 2001; Parr et al., 2011; Sarantonio and Gallandt, 2003), but their use in perennial systems such as orchards and vineyards remains limited and deserves further study as growers seek sustainable orchard management systems with a goal of developing a system beneficial to the health of both the trees and the soil in which they grow (Reganold et al., 2001).

Nutrient management is important to successful and sustainable apple production. Nitrogen is generally considered the limiting factor, and therefore seeking ways to provide sufficient N to apple trees with the appropriate delivery time has been the topic of some but insufficient research (Granatstein and Sanchez, 2009). Studies have shown that apple trees perform poorly with competitive vegetation (Atkinson et al., 1977; Atucha et al., 2011). Therefore, the standard management approach in conventional orchards is to maintain an herbicide strip under the trees, and often a marginally managed grass drive alley. In organic systems, the primary management practice is surface cultivation of the tree-row soil for weed management, and a grass alley. Some orchardists use a different approach, in which the drive-alley is planted in leguminous cover crops, or mixes of legumes and grasses which get mowed periodically and clippings are assumed to provide N to the trees (personal communication, C. R. Rom, 2014).

The studies that have been done on this subject have in many cases failed to isolate single crops and have instead investigated cover crop mixes, which make assessment of specific contributions difficult. In some tests, cover crops were cut and dropped in the drive alley (Sánchez, 2006), or cover crops were examined as living mulches in the tree row (Hoagland et al., 2008; Merwin et al., 1994; TerAvest et al., 2010; Yao et al., 2005).

The premise of the study was that due to the non-competitive nature of apple tree roots and the relative lack of lateral movement of N in the soil, N-fixing cover crops grown in the drive alley would not provide apple trees with significant nitrogen. However, a well-managed mow/blow approach, in which N-fixing cover crops are grown in the drive row, and mown and blown onto the tree row, may provide available N delivered for root uptake.

Hypotheses: This study examines the use of drive row cover crops in an apple orchard as a means of providing a nutrient benefit to the trees. It was the hypothesis of this study that nitrogen would be biologically sequestered by orchard drive-row cover crops but would not be available for utilization by apple trees. A second hypothesis was that it may be possible, however, to use that nutrient source more effectively through a mow/blow treatment, delivering the cover crop biomass to the tree row as mulch. An additional hypothesis of the study was that cover crop management would affect soil quality and nutrient content, tree growth, and nutrition.

Materials and Methods

General Experimental Conditions

Location and Site: The research was conducted at the University of Arkansas System Division of Agriculture Research and Extension Center, Horticultural Research Station in Fayetteville, Arkansas (36°6.146’ W, -94°10.122’N). The 24 x 56 m site had been previously used as an apple orchard for approximately eight years, but the orchard was removed two years prior to the onset of the study during which time the land was unmanaged. The site consisted of approximately

90% Pembroke silt loam (moderately well-drained, typic Paleudult, fine-silty, mixed, thermic) and 10% Captina silt loam (moderately well-drained, Fragiudult, fine-silty, siliceous, mesic) (Appendix A.5). The soil pH at the study onset ranged from 4.69-5.61 and the average organic matter was 3.78%. An existing orchard trellis and irrigation lines were utilized. Dolomitic lime was applied in December 2012 at a rate of 4483 kg/ha based upon the soil assessment.

Plant Materials: In March 2012, 185 ‘Bud.9’ apple rootstocks were planted, at 2 m x 4 m spacing, and chip budded with a University of Arkansas breeding selection AA134 after planting. Due to extreme weather conditions in 2012 (www.nws.noaa.gov/climate/), there was low graft success and considerable rootstock mortality. Dead plants were replaced and failed grafts were rebudded in September, 2012. In May 2013, rootstocks that had not been successfully budded were rebudded by T-budding.

Treatments and experimental design

Treatments: Three ground cover management cycle treatments were installed:1) winter/summer legume cover crop cycle; 2) winter/summer grass cover crop cycle, and 3) bare ground/native natural vegetation. Main plots were split for 1 of 2 split plots of:A) control, and B) mow/blow. The split plots were randomized within main effect treatment plantings. This resulted in a total of six cover crop treatments which were each replicated 4 times. Three seasons of cover crop plantings were assessed.

Layout, experimental design, and statistical analyses: The study area was comprised of six trellised rows and was divided into four randomized complete blocks, with each block containing every treatment and sub-treatment (Appendix A.1). Each block consisted of three main treatments across three tree rows, of which the outer two rows functioned as guard rows. An experimental unit was an individual tree. Data trees were separated by guard trees within row and within treatment, so that two guard trees separated main treatment margins. Statistical analyses used SAS (Cary, S.C.) software, and used Kenwood-Roger and Tukey-Kramer for mean separations with PROC GLM and PROC GLIMMIX

The legume cover crop for summer 2012 and summer 2013 plantings was ‘Iron Clay’ cowpea (*Vigna unguiculata*), and the winter legume, seeded in September 2012, was ‘AU Robin’ crimson clover (*Trifolium incarnatum*). Cowpea seeds were coated with EL Type inoculant, and crimson clover treated with B Type inoculant from Hancock Seeds (Dade City, FL) prior to planting. The summer grass cover crop was German foxtail millet (*Setaria italica*), and the winter grass was ‘Gulf’ annual rye (*Lolium multiflorum*). Prior to planting, soils of all treatments were cultivated in May 2012 and again in September 2012 and then seed drilled at 25-30 kg/ha. The control bare ground treatment plots were cultivated at planting, in which naturally existing vegetation would emerge during the seasonal crop cycle. At the end of each cover crop cycle, crops were mowed with a tractor rotary cutter to be dropped in place or blown to the tree row with a side-deposit mower in a width of approximately 1 m, 0.5 m on either side of the trees. In June 2013 the soil was not cultivated prior to planting and seeds were drilled into the remaining crop detritus.

Treatments not receiving mow-blow were hand-raked to evenly distribute biomass. Crop biomass samples were collected immediately for dry weight and foliar analysis from a 0.25-m quadrat from three random locations per block. Glyphosate herbicide (Roundup®, 1%) was sprayed to control weed competition in tree rows (September 2012 and June 2013) in a 1-m width band (0.5 m on either side of the tree) as well as on weed/bare ground treatment in July 2012 and June 2013. To control grass competition in August 2013 after mowing and prior to fall cover crop seeding, the herbicide sethoxydim (Poast®) was sprayed on all drive rows in the experimental area, and followed 3 weeks later with spot applications of glyphosate to control cowpea regrowth and in-row broadleaf weed competition.

Measurement Variables

Soil characteristics: Soil bulk density and organic matter were assessed in October 2011 as the plot was being prepared, after initial cultivation and prior to cover crop planting. One 2 cm (width) x 10 cm (depth) core was taken from each of 36 locations across the plot. Sampling locations were selected by taking one sample from each north-south tree row (along irrigation lines) for every other east-west row (referred to as CrossRow) across the site perpendicular to irrigation lines (Appendix A.8). Samples were oven-dried, weighed, and soil bulk density calculated as dry weight/core volume (g/cm^3). Organic matter percentage by weight was calculated by change in weight after kiln drying for two hours at 360°C. Subsamples were analyzed by the Soil and Foliar Testing Agricultural Service Unit, University of Arkansas Division of Agriculture, Altheimer Laboratory, Fayetteville, Arkansas, for nutrient analysis after Mehlich-3 digestion and analysis by inductively coupled plasma photospectrometry. All soil samples and measurements were repeated in September 2013.

Soil samples [2 cm (width) x 10 cm (depth) core] were collected from two locations (21-May, 2012; 20-Sep, 2012; 23-May, 2013; 18-Sep, 2013) 30 days after each cover crop harvest for each data tree:1) 15 cm south of the base of the tree (within the Tree Row) and 1.5 m east of each data tree (within the Drive Row). Soils were placed in plastic bags and stored in a cooler during collection and then refrigerated at 4°C. Soil samples were processed through a #2mm sieve and a subsample was stored at 4°C for labile C and N analyses, and a subsample oven dried for 24 hours at 105 °C to determine gravimetric moisture content and for soil C and N analyses.

Soil carbon (C) and nitrogen (N): After drying, samples were ground to a powder with a mortar and pestle. For total C and N analysis with an Elementar Vario EL Cube catalytic combustion elemental analyzer (Elementar Americas, Inc., USA), 40 mg subsamples were combusted at 1200°C.

Soil labile carbon and nitrogen: Based upon findings of Curtin et al., (2005), soil was sampled on 27 May, 2012, the day after seeding cover crop treatments. Samples were processed using a modified version (Savin, personal communication) of the procedure described by Ghani et al., (2003):3g field moist soil was transferred to 40-ml centrifuge tubes, and 30 ml of MQ H_2O added. Each tube was mixed with a vortex mixer for 10 seconds and then incubated for 16 hours in an 80 °C water bath. Upon removal, samples were mixed with a vortex mixer and centrifuged at 3500rcf for 20 minutes. Supernatant was filtered through a 0.25 μm cellulose membrane filter into 40-ml glass vials, transferred to clean centrifuge tubes, frozen at -18°C, and defrosted 12 hours prior to analysis with a TOC-VCSH Total Carbon Analyzer with an attached TMM-1 Total Nitrogen Measuring Unit and an ASI-V automatic sampler (Shimadzu Scientific Instruments America, Columbia, MD). Results are expressed μg N or C/g soil**.**

Volumetric water content: Soil water content was measured weekly through the 2013 summer growth season at tree row and drive row soil sampling sites using a FieldScout TDR300 Soil Moisture Meter (Spectrum Technologies Inc. Aurora, IL). The probe rod length was 12cm. measured in Standard mode, where measurements are reported as percentage volumetric water content (VWC%) within the sampled depth.

Plant characteristics: Cover crop samples were collected immediately after crop harvest at each harvest date (23-August 2012, 24-April 2013, and 21-August 2013) using a 0.0625-m^2 hoop and sampling three random locations per block. Apple tree foliage samples were collected in September 2013 using all trees in each row within a plot to obtain composite samples for each treatment. Plant samples were dried for 72 hours at 60 °C and weighed for biomass then ground to pass through a 1-mm mesh screen. Plant tissue C and N (10 mg) were analyzed as described for soil C and N.

Results

Cover Crop Biomass and Nutrient Content: It was observed but unmeasured that there was a light but incomplete stand of cover crops after an autumn 2011 planting. Therefore, although the study had been initiated, no data were collected in the 2011 season. The first cover crop data were collected following the summer 2012 treatment establishment. Cowpea and millet biomass (Table 3.1) were similar in the summer 2012, averaging 591.2 g/m^2 for cowpeas and 472.8 g/m^2 for millet. The control treatment of natural vegetation biomass was less than millet or cowpea. In the winter cover crop cycle for 2012/2013, crimson clover had significantly higher %N than rye (Table 3.2). Crimson clover produced significantly more biomass (389.3 g/m^2) than either of the other treatments which also resulted in greater total N and C than other treatments. Annual rye produced 153 g/m^2 and winter natural vegetation produced only 91 g/m^2.

The summer 2012 (Table 3.1) cowpeas had a tissue N content of 2.1 %, producing 12 g N/m^2 of cover crop- extrapolated from sample size, this crop could produce 120 kg N/ha of cover crop. Millet had significantly less tissue N than either legumes or natural vegetation, with 1.3 %N, or 6.1 g N/m^2 (60.8 kg/ha). Natural vegetation had greater foliar (or total above-ground biomass) N concentration than millet, but because biomass was less, total N per unit land was less than either millet or cowpea. Cowpea tissue analysis had significantly lower %C than the other treatments. Millet had the a similar total C contribution per unit land area, while the natural vegetation had statistically similar %C to millet but less total C contribution than cowpea or millet.

Although the winter 2012/2013 (Table 3.2) cover crops established well, a preharvest visual assessment revealed minimal root nodulation on crimson clover despite preplant inoculations (data not shown). Tissue N content was similar for crimson clover and annual rye but significantly lower levels of tissue N for the natural vegetation. Because of significant differences in biomass among treatments, the total N contribution per unit land area was significantly different among treatments. Percent carbon tissue content was similar for all treatments, but total C contribution was different because of differing biomass. Crimson clover had more than double the total C contribution than either rye or natural vegetation.

In summer of 2013 (Table 3.3), affected by drought-induced establishment issues (Appendix A.6), cowpeas did not have robust growth. However, as previously observed (Table 3.1), cowpeas contained more tissue N than other treatments, and due to producing nearly double the biomass of millet, yielded higher total N, while millet and natural vegetation had statistically similar tissue %N and total N contribution (Table 3.3). Carbon tissue content was similar for all treatments, but because cowpeas had higher biomass, the total C contribution was significantly higher than other treatments, while millet and natural vegetation had statistically similar C contributions.

<u>Soil Nutrient Analyses:</u> Soils sampled in May 2012 (Table 3.4) showed no significant differences in %N, %C, or C:N ratio by treatment. No cover crops had been grown in the plots at that point, but a significant difference by location had less labile N in the tree row than found in the drive

row, and a corresponding difference in labile C:N. This difference could possibly be attributed to release of N from decomposing natural vegetation that had been disked into the drive rows the previous fall during site preparation. After the summer cover crop cycle of cowpeas and millet (Table 3.5), soils sampled October 2012 showed a significant difference in C:N ratio between treatments. Legume cover crops generated the lowest soil C:N ratio of the treatments compared to grasses and natural vegetation. There was a statistically significant interaction between treatment (cover crop) and location (tree row or drive row) in which grass drive row had similar %N as legume tree row and slightly higher %N than other combinations (Table 3.6). Additionally, a significant interaction between treatment, application, and location demonstrated labile N concentration where legumes were mulched to the tree row was statistically similar to legumes mulched to the drive row, legumes with no mulch in the drive row, and natural vegetation mulched to the drive row, and statistically greater labile N than all other combinations. It is worth noting that in this interaction, some of the least labile N content was measured where legumes were grown in the drive row and then mulched to the tree row, leaving no decomposing above ground plant fractions in the drive row.

After two seasons and crop rotations, soils sampled in June 2013 showed continuing shifts in C:N ratio of the total C and N pools (Table 3.7). The C:N ratio was lowest where cover crops were grown and mulched to the soil surface when compared to being raked away and was lower in the tree row than the drive row. Soils growing legume cover crops had significantly greater labile soil N than soils growing grass cover crops. Additionally, soil labile N was greater where cover crops were mulched, and labile C:N ratio was lower. Legume treatments had higher labile N and lower labile C:N ratio than grass treatments. A cover crop treatment by application (mulch or no mulch) interaction showed significantly greater N for mulched legumes, as well as the lowest labile C:N ratio for that combination of variables in the tree row soil (Table 3.8). Additionally, soil labile N was the greatest where cover crops were mulched to the tree row compared to other treatment combinations.

Soils sampled in September 2013 after the summer cover crop rotation had differences in C:N ratio among treatments; soils where legumes had grown had a lower C:N ratio than grasses and the tree row had lower C:N than the drive row (Table 3.9). This data collection came after a dry late summer (appendix A.7) in which cover crops did not appear to degrade after harvest, and the only significant difference in the labile pool was a shift in C:N ratio by location, in which soils within tree row had greater C:N than soils within the drive row.

Soil Moisture:Volumetric soil water content (SWC) measured weekly throughout the summer of 2013 (Appendix A.7) indicated differences between the tree row and drive row but no significant differences by treatment.

Apple Trees: Low graft success in 2012 due to heat and drought (Appendix A.6) necessitated repeated grafting of apple trees, preventing data collection of tree growth. However, by the conclusion of the summer 2013 season there were healthy trees for foliar sampling for C and N analysis (Table 3.10). There were significant differences by main effect treatment (cover crop species). Legume treatments produced statistically higher apple foliar N content than the millet treatment or natural vegetation. Tissue C levels were statistically similar for all treatments.

Discussion and Summary

Legume cover crops, biologically fixing atmospheric nitrogen, contained expectedly higher nitrogen (as a percentage of dry plant weight as well as per square meter of orchard soil) than grass/grain cover crops, supporting previous findings by Rannels and Wagger (1996). Some researchers advocate for using mixes of legumes and grasses for optimal cover crop benefits of both nitrogen generation and nutrient scavenging/retention (Fageria, 2005). It was the aim of our study to address the more basic issue of whether the cover crops initiated/caused short-term changes in soil carbon and nitrogen based on location of the cover crop and plant biomass decomposition, comparing legumes against grasses. Our winter legume cover crop, crimson clover, produced an estimated 100 kg N/ha^{-1}, which is somewhat lower than other estimates. Evers and Parsons (2011) found that crimson clover grown in Texas produced an average of 189 kg N/ha^{-1} over two years of study, while Rannels and Wagger (1996) reported crimson clover N fixation of 134 kg N/ha^{-1}. Rannels and Wagger (1992) reported 67 kg/ha of N released at 8-week retrieval when harvested at a similar maturity stage to the current study.

Iron Clay cowpeas, the summer legume tested, averaged 519 g/m^2 dry weight biomass over two seasons, while Harrison et al., (1996) averaged 475 g/m^2 over two years of a study in South Carolina, growing in sandy loam with lower organic matter than measured in our study. While orchard alleys are generally mowed grass (Granatstein and Sanchez, 2009), recent studies have examined the use of alley cover crops with mow/blow treatments (Kuhn and Pedersen, 2009, Sanchez et al., 2003). Our study assessed primarily changes in soil characteristics and nutrient status, both over time (only 2 years) and by treatment, in addition to assessing contributions from cover crops.

Because of slow establishment of fruit trees, growth measurements such as trunk cross-sectional area and shoot growth did not fit within the time-frame of this study. However, foliar sampling conducted in September 2012 indicated significantly higher nitrogen content for trees grown with legume cover crop main effect treatments than those grown with grass/grains or the untreated control. In a publication on nutritional sufficiency ranges for crops, Plank (1996), places the sufficient foliar N range for apples at 1.9-2.3% and Shear and Faust (1980) placed the foliar N sufficiency range from 1.7-2.5%. In our study, the samples from legume plots averaged 2.0% N in the middle to high range, while those from grain plots measured 1.7% N, or in the lower levels of sufficiency. Kuhn and Pedersen (1999) also found significant differences in apple foliar N between plots grown with legumes and grasses, although both were within sufficiency range (2.60% with legumes and 2.08% with grasses). The current work corroborates that of Khun and Pedersen (1999).

Interestingly, there are very few studies examining changes to orchard soil N pools as a result of legume cover crop mulches and so there are limits of comparison of the current study. Although total cover crop biomass was not measured, TerAvest (2009) did not find significant differences in total soil N or C between legume and non-legume in-row cover crops in an apple orchard, and in olive orchards there were short-lived increases in soil N, although the proximity of cover crop residue to olive tree was unclear (Rodrigues et al., 2013). After two seasons of cover crops, labile N was significantly higher in legume treatments than grass, and while the longevity of that shift was not measured, the timing of sampling was planned to coincide with normal late season tree uptake of nitrogen, as defined by Tagliavini and Millard (2005). To observe larger changes in the total C and N pools may require a sustained period of year-round cover cropping that exceeds the time-frame of this study. We examined the total C and N pools with the intention of the experiment continuing far past the duration of this thesis work, as changes to total pools tend to happen slowly. The examination of labile pools gave us a view of short-term shifts and a better idea of plant-available nutrients.

After two seasons of cover crops, our study showed significant differences supporting the original hypotheses:higher labile N and lower C:N in both total and labile pools occurred where cover crops were mulched rather than removed, higher labile N and C:N occurred when the mulches were legumes, and higher labile N occurred when that mulch was in the tree row rather than the drive row, in addition to greater foliar N for trees grown in legume treatments. These data indicate that unless nutrients from the cover crops are delivered to the tree root zone, they provide less of a potential benefit. However, lower organic matter at the conclusion of the study, and variable results from sampling date to sampling date for soil carbon and nitrogen analysis largely point to needing additional studies to confirm observations and demonstrate how to manage the cover crops appropriately to garner maximum benefit.

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Table 3.1. Tissue nitrogen and carbon concentration, biomass, and carbon and nitrogen content per area of 3 cover crop treatments in a developing apple orchard, Fayetteville, AR, August, 2012 after 86 days growth.

Treatment	% N	% C	Biomass Dry Weight (g/m^2)	Total N contribution (g/m^2)	Total C contribution (g/m^2)
Cowpea	2.1a[z]	27.7b	591.2a	12.0a	161.3a
Millet	1.3c	37.9a	472.8a	6.1b	179.3a
Natural Vegetation	1.6b	34.4a	291.3b	4.7b	100.1b

[z]Mean separation within columns by LSD test. Means within columns followed by different letters are significantly different ($p \leq 0.05$). n=12

Table 3.2. Tissue, nitrogen and carbon concentration, biomass, and carbon and nitrogen content per area of 3 cover crop treatments in a developing apple orchard, Fayetteville, AR, April, 2013 after 217 days growth.

Treatment	% N	% C	Biomass Dry Weight (g/m^2)	Total N Contribution (g/m^2)	Total C Contribution (g/m^2)
Crimson Clover	2.6a [z]	40.9	389.3a	10.1a	160.1a
Annual Rye	1.6b	41.8	153.3b	2.4b	62.3b
Natural Vegetation	2.5a	41.6	90.8c	2.3b	36.8c
		ns			

[z]Mean separation within columns by LSD test. Means within columns followed by different letters are significantly different ($p \leq 0.05$). ns= no significant difference among means within a column. n=12

Table 3.3. *Tissue nitrogen and carbon concentration, biomass, and carbon and nitrogen content per area of 3 cover crop treatments in a developing apple orchard, Fayetteville, AR, August 2013 after 70 days growth.*

Treatment	% N	% C	Biomass Dry Weight (g/m^2)	Total N contribution (g/m^2)	Total C contribution (g/m^2)
Cowpea	2.0a [z]	40.7	446.7a	9.1a	181.8a
Millet	1.4b	41.8	242.9b	3.4b	101.6b
Natural Vegetation	1.8b	41.6	194.2b	3.5b	80.7b
		ns			

[z]Mean separation within columns by LSD test. Means within columns followed by different letters are significantly different ($p \leq 0.05$). ns= no significant difference among means within a column. n=12

Table 3.4. Effects of drive row cover crop treatments and mow/blow mulch treatments on total carbon and nitrogen, C/N ratio, labile carbon and nitrogen, and labile C/N ratio of soils of an orchard in Fayetteville, AR, May, 2012. Initial soil assessment prior to cover crop treaments.

Treatment	%N	%C	C:N	Labile N (µg N/g soil)	Labile C (µg C/g soil)	Labile C:N
			Cover Crop Treatment			
Legume	0.12[z]	0.57	4.59	27.74	132.78	5.31
Grass	0.13	0.72	6.20	31.87	181.99	6.21
Natural Vegetation	0.12	0.60	4.94	31.23	167.46	5.76
n=16	ns	ns	ns	ns	ns	Ns
			Mulch Application Treatment			
Mulch	0.13	0.73	5.71	31.28	164.69	5.81
No Mulch	0.12	0.58	4.78	29.28	156.80	5.71
n=24	ns	ns	ns	ns	ns	Ns
			Sample Location			
Tree Row	0.12	0.72	5.66	24.64b	190.29	7.78a
Drive Row	0.12	0.59	4.82	35.92a	131.20	3.74b
n=24	ns	ns	ns		ns	

[z]Mean separation within columns by Kenwood-Roger. Means followed by different letters are significantly different ($p \leq 0.05$). ns= no significant difference among means within a column and treatment level.

Table 3.5. Effects of one season of summer cover crops and mow/blow treatments on total carbon and nitrogen, C/N ratio, labile carbon and nitrogen, and labile C/N ratio of soils of an orchard in Fayetteville, AR, October, 2012

Treatment	%N	%C	C:N	Labile N (µg N/g soil)	Labile C (µg C/g soil)	Labile C:N
			Cover Crop Treatment			
Legume	0.09[z]	0.80	9.42b	50.24a	269.44	5.52b
Grass	0.08	0.92	10.04a	42.89b	285.94	6.77a
Natural Vegetation	0.09	0.83	9.95a	44.23ab	285.08	6.73a
n=16	ns	ns			ns	
			Mulch Application Treatment			
Mulch	0.09	0.86	9.71	48.87	287.58	9.71
No Mulch	0.09	0.84	9.70	42.71	272.74	9.90
n=24	ns	ns	ns	ns	ns	ns
			Sample Location			
Tree Row	0.09	0.84	9.68	42.13b	287.73	6.98a
Drive Row	0.09	0.86	9.92	49.44a	272.58	5.71b
n=24	ns	ns	ns		ns	

[z]Mean separation within columns by Kenwood-Roger. Means within columns followed by different letters are significantly different ($p \leq 0.05$). ns= no significant difference among means within a column and treatment level.

Table 3.6 Interactions of effects of one season of summer cover crops and mow/blow treatments on total carbon and nitrogen, C/N ratio, labile carbon and nitrogen, and labile C/N ratio of soils of an orchard in Fayetteville, AR, October, 2012

Treatment*Location		%N
Legume	TreeRow	0.09ab[z]
Legume	DriveRow	0.08b
Grass	TreeRow	0.09b
Grass	DriveRow	0.1a
Weed	TreeRow	0.09b
Weed	DriveRow	0.08b

Treatment*Application*Location			Labile N (µg N/g soil)
Legume	Mulch	TreeRow	61.3a
Legume	Mulch	DriveRow	53.5ab
Legume	NoMulch	TreeRow	34.3d
Legume	NoMulch	DriveRow	51.9abc
Grass	Mulch	TreeRow	35.9d
Grass	Mulch	DriveRow	46.8bcd
Grass	NoMulch	TreeRow	42.2bcd
Grass	NoMulch	DriveRow	46.7bcd
Weed	Mulch	TreeRow	41.2bcd
Weed	Mulch	DriveRow	54.5ab
Weed	NoMulch	TreeRow	38cd
Weed	NoMulch	DriveRow	43.2bcd

[z]Mean separation within columns by Kenwood-Roger, SAS Corp, Cary, N.C. Means followed by different letters are significantly different ($p \leq 0.05$)

Table 3.7. Effects of two seasons of cover crops (summer and winter) and mow/blow treatments on total carbon and nitrogen, C/N ratio, labile carbon and nitrogen, and labile C/N ratio of soils of an orchard in Fayetteville, AR, June 2013.

Treatment	%N	%C	C:N	Labile N (µg N/g soil)	Labile C (µg C/g soil)	Labile C:N
			Cover Crop Treatment			
Legume	0.09[z]	0.80	9.15	40.13a	270.79	7.56b
Grass	0.08	0.77	9.38	25.99b	257.17	10.05a
Natural Vegetation	0.08	0.80	9.50	30.58ab	273.24	9.26a
n=16	ns	ns	ns		ns	
			Mulch Application Treatment			
Mulch	0.08	0.78	9.18b	36.83a	277.49	8.27b
No Mulch	0.08	0.80	9.51a	27.63b	256.64	9.65a
n=24	ns	ns		(p <0.001)	ns	(p <0.001)
			Sample Location			
Tree Row	0.08	0.78	9.22b	33.43	271.87	9.12
Drive Row	0.08	0.79	9.47a	30.94	262.25	8.80
n=24	ns	ns		ns	ns	ns

[z]Mean separation within columns by Kenwood-Roger. Means followed by different letters are significantly different ($p \leq 0.05$ except where noted). ns= no significant difference among means within a column and treatment level.

Table 3.8. Interactions of effects of two seasons of cover crops (summer and winter) and mow/blow treatments on total carbon and nitrogen, C/N ratio, labile carbon and nitrogen, and labile C/N ratio of soils of an orchard in Fayetteville, AR, June 2013.

Treatment*Application		Labile N (µg N/g soil)	Labile C:N ratio
Legume	Mulch	49.23a	6.20b
Legume	NoMulch	31.02b	8.93a
Grass	Mulch	27.54b	9.67a
Grass	NoMulch	24.44b	10.43a
Weed	Mulch	33.73b	8.94a
Weed	NoMulch	27.44b	9.57a

Application*Location			
Mulch	TreeRow	42.18a	
Mulch	DriveRow	31.48b	
NoMulch	TreeRow	24.87b	
NoMulch	DriveRow	30.40b	

[z]Mean separation within columns by Kenwood-Roger. Means followed by different letters are significantly different ($p \leq 0.05$).

Table 3.9. Effects of three seasons of drive row cover crops (two summer and one winter) and mow/blow treatments on total carbon and nitrogen, C/N ratio, labile carbon and nitrogen, and labile C/N ratio of soils of an orchard in Fayetteville, AR, September 2013

Treatment	%N	%C	C:N	Labile N (µg N/g soil)	Labile C (µg C/g soil)	Labile C:N
			Cover Crop Treatment			
Legume	0.08	0.77	9.73b	46.28	273.22	6.21
Grass	0.08	0.84	10.19a	40.82	299.39	7.24
Natural Vegetation	0.09	0.88	10.02ab	42.16	306.97	7.31
n=16	ns	ns		ns	ns	Ns
			Mulch Application Treatment			
Mulch	0.08	0.82	9.94	43.77	294.07	6.87
No Mulch	0.08	0.84	10.01	42.40	291.32	6.98
n=24	ns	ns	ns	ns	ns	Ns
			Sample Location			
Tree Row	0.08	0.82	9.84b	40.93	298.53	7.33a
Drive Row	0.08	0.84	10.11a	45.25	287.86	6.52b
n=24	ns	ns		ns	ns	

Mean separation within columns by Kenwood-Roger. Means followed by different letters are significantly different ($p<0.05$). ns= no significant difference among means within a column and treatment level.

Table 3.10 Foliar carbon and nitrogen of young apple trees grown with drive-row cover crop treatments in a newly established orchard in Fayetteville, AR September 2013

Treatment	%N	%C
Grass	1.7b^{z}	45.6
Legume	2.0a	45.5
Natural Vegetation	1.9ab	45.9
		ns

^{z}Mean separation within columns by LSD, SAS Corp, Cary, N.C. Means within columns followed by different letters are significantly different ($p \leq 0.05$). ns= no significant difference among means. n=4

CHAPTER 4: General Discussion and Conclusions

The objectives of these studies were to examine cover crop competition with apple trees in a controlled environment, and measure nitrogen changes to apple trees grown with legume and grass mulches in that environment, and established an orchard to examine the effects of grass and legume drive row cover crops on tree and soil nutrients. The greenhouse study confirmed previous research into the response of apple trees to root zone competition, showing decreased growth, poor health, and lower nutrient levels when grown with either grasses or legumes. Additionally, apple trees grown with legume mulches showed increased shoot growth, greater leaf area, and higher tissue nitrogen than those grown with identical fertilizer regimens but no legume mulches. Interestingly, trees grown with cover crop competition showed some signs of growth recovery post-crop harvest, which Atucha et al. (2011) reported in a long-term orchard study in which inhibitory effects of cover crop competition were overcome by compensatory tree growth over the long-term in the orchard environment.

Although there have been an increasing number of field studies examining cover crop use with perennial/permanent crops, few have begun to look at soil nutrient changes as a result of cover crop use, nor specifically compared grass and legume cover crops. This study laid out a methodology for doing so, and showed promising nitrogen management techniques for apple orchards, but ultimately requires longer periods of study to confirm consistency of results. It may be useful to consider a similar study in an established orchard, where changes to fruit tree nutrient status could be measured more thoroughly and accurately. Managing the establishment of newly planted, field grafted trees in the midst of cover crop treatment plots added some unforeseen challenges to the process.

This study did not question or address practical management implications of cover crop species choice. We examined the fundamental issue of the differences in nutrient contribution between grass and legume cover crops using commercially accessible species with a regional history as representative species. Future studies, in addition to building longer-term study periods for more consistent results, would need to address crop management issues such as how well crops withstand machinery traffic and how to address potential water needs of various cover crop choices.

Literature Cited

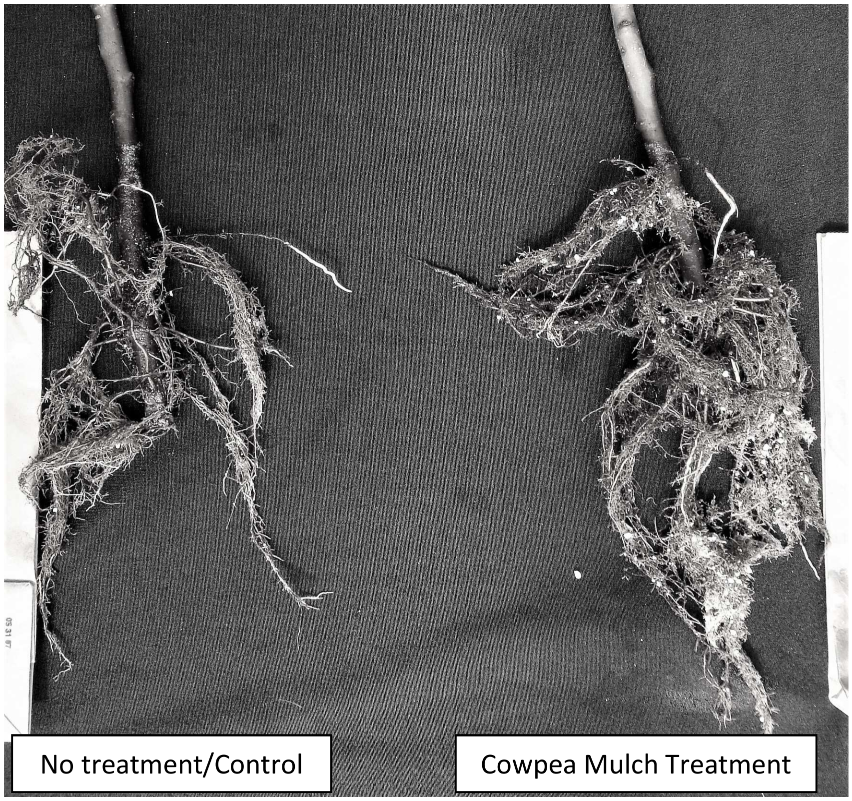
Atucha, A., I.A. Merwin, and M.G. Brown. 2011. Long-term effects of four groundcover management systems in an apple orchard. HortScience 46:1176-1183.

APPENDICES

Appendix A.1. *Saturation extract analysis of potting media comprised of equal parts sand, vermiculite, and perlite with apple trees subjected to cover crop and mulch treatments in a Quonset Greenhouse in Fayetteville, AR. August 2013. Treatments: CP=cowpea competition, FM=foxtail millet competition, CPM=cowpea mulch, FMM=foxtail millet mulch, NT=control/no treatment*

	Treatments				
Media Effluent Characteristics	CP	FM	CPM	FMM	NT
pH	6.3	7.0	6.9	7.6	7.6
EC(µmhos/cm)	658	449	379	211	250
NO_3-N (mg/l)	42.7	15.9	17.3	2.6	6.9
P (mg/l)	5.2	8.9	4.7	4.7	5.0
K (mg/l)	117.6	63.1	67.9	31.5	27.8
Ca (mg/l)	14.7	10.9	7.0	4.4	5.0
Mg (mg/l)	13.1	12.4	16.2	12.1	11.9
Na (mg/l)	18.1	24.5	19.5	15.8	22.2
S (mg/l)	16.7	12.0	8.4	5.1	7.4
Fe (mg/l)	2.6	3.6	10.9	9.3	7.4
Mn (mg/l)	0.15	0.07	0.18	0.16	0.11
Zn (mg/l)	0.24	0.16	0.31	0.22	0.18
Cu (mg/l)	0.04	0.03	0.05	0.03	0.02
B (mg/l)	0.16	0.11	0.19	0.1	0.09
NH_4-N (mg/l)	0.65	0.59	0.62	0.5	0.53

Appendix A.2 *Apple roots after 73 days with no treatment/control (NT) on left and cowpea mulch (CPM) treatments on right when grown in a controlled environment.*



Appendix A.3 *Apple tree after 73 days with cowpea mulch (CPM) treatment when grown in a controlled environment.*

Appendex A.4 Plot map for field study of the effects of rotational cover crops on the growth and development of young apple trees, Fayetteville, AR, 2012-2013, showing cover crop treatment locations, data trees (numbered), and guard trees (°).

Orchard Dimensions

Length= 185'

Width=75'

Rows=6

North

Tree Row

	o	o	o	o	o	o	
	67	68mb	69	70	71mb	72	
	o	o	o	o	o	o	
	61mb	62	63mb	64mb	65	66mb	
	o	o	o	o	o	o	
	o	o	o	o	o	o	
Block	55	56mb	57	58	59mb	60	Block
III	o	o	o	o	o	o	II
	49mb	50	51mb	52mb	53	54mb	
	o	o	o	o	o	o	
	o	o	o	o	o	o	
	43	44mb	45	46mb	47	48	
	o	o	o	o	o	o	
	37mb	38	39mb	40	41mb	42mb	
	o	o	o	o	o	o	
	o	o	o	o	o	o	
	31	32	33mb	34	35	36mb	
	o	o	o	o	o	o	
	25mb	26mb	27	28mb	29mb	30	
	o	o	o	o	o	o	
	o	o	o	o	o	o	
Block	19	20mb	21	22mb	23mb	24	Block
IV	o	o	o	o	o	o	I
	13mb	14	15mb	16	17	18mb	
	o	o	o	o	o	o	
	o	o	o	o	o	o	
	7	8mb	9mb	10	11mb	12	
	o	o	o	o	o	o	
	1mb	2	3	4mb	5	6mb	
	o	o	o	o	o	o	

Tree Row

South

Treatments

Winter Cover Crop

Ryegrass

mb= displaced mulch

Red Clover

mb=displaced mulch

Control- Native Vegetation

Summer Cover Crop

Foxtail Millet

mb=displaced mulch

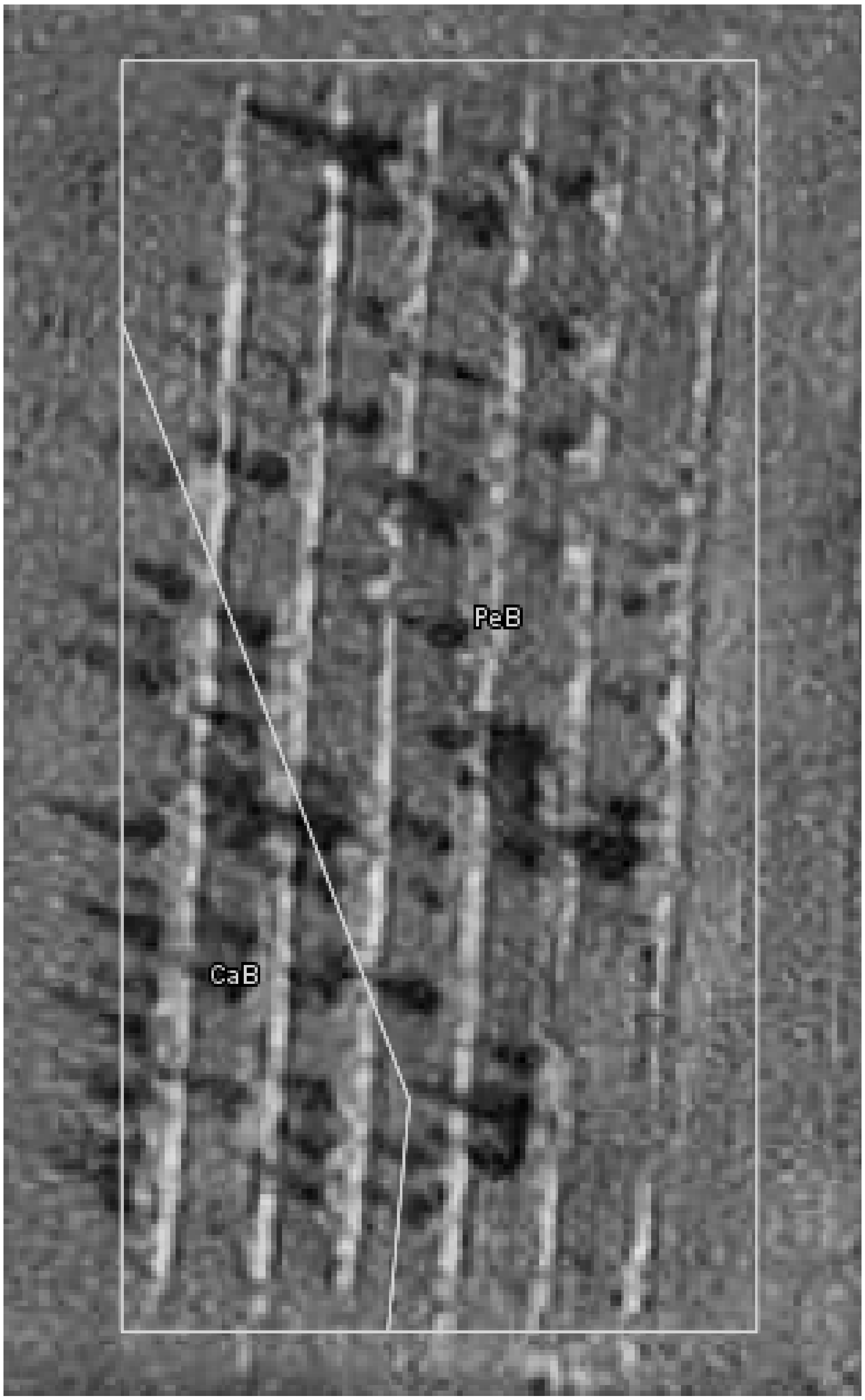
Cowpeas

mb=displaced mulch

Control- Native Vegetation

mb=displaced mulch

Appendix A.5. *Aerial photograph and soils map (http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx 28-Sep 2016) for field study of the effects of rotational cover crops on the growth and development of young apple trees, Fayetteville, AR, 2012-2013 CaB= Captina Silt Loam PeB= Pembroke Silt Loam*

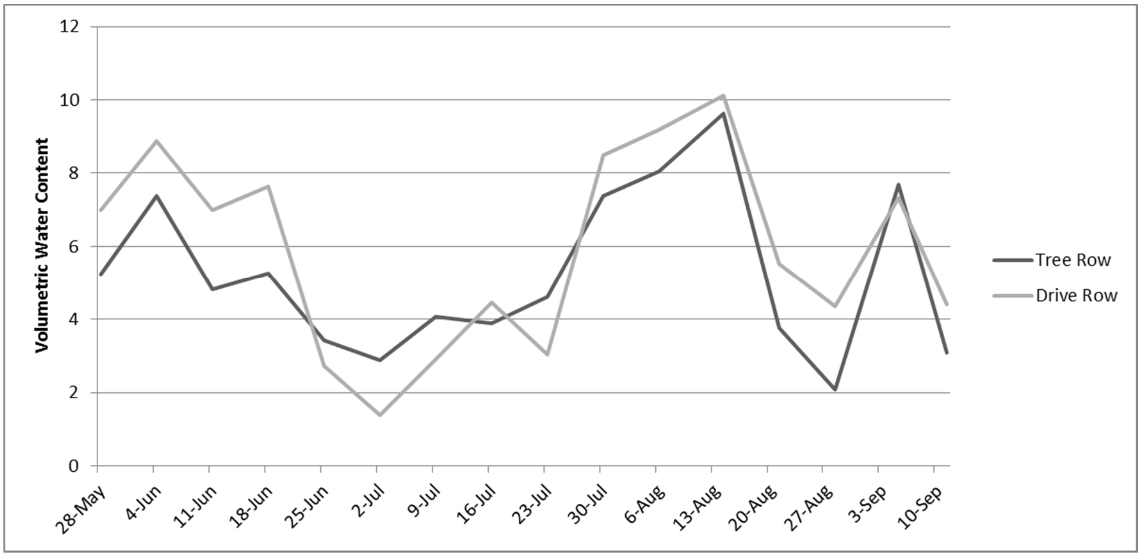


Appendix A.6. *Monthly temperature and precipitation for the Fayetteville Experimental Station, 2011-2013.*

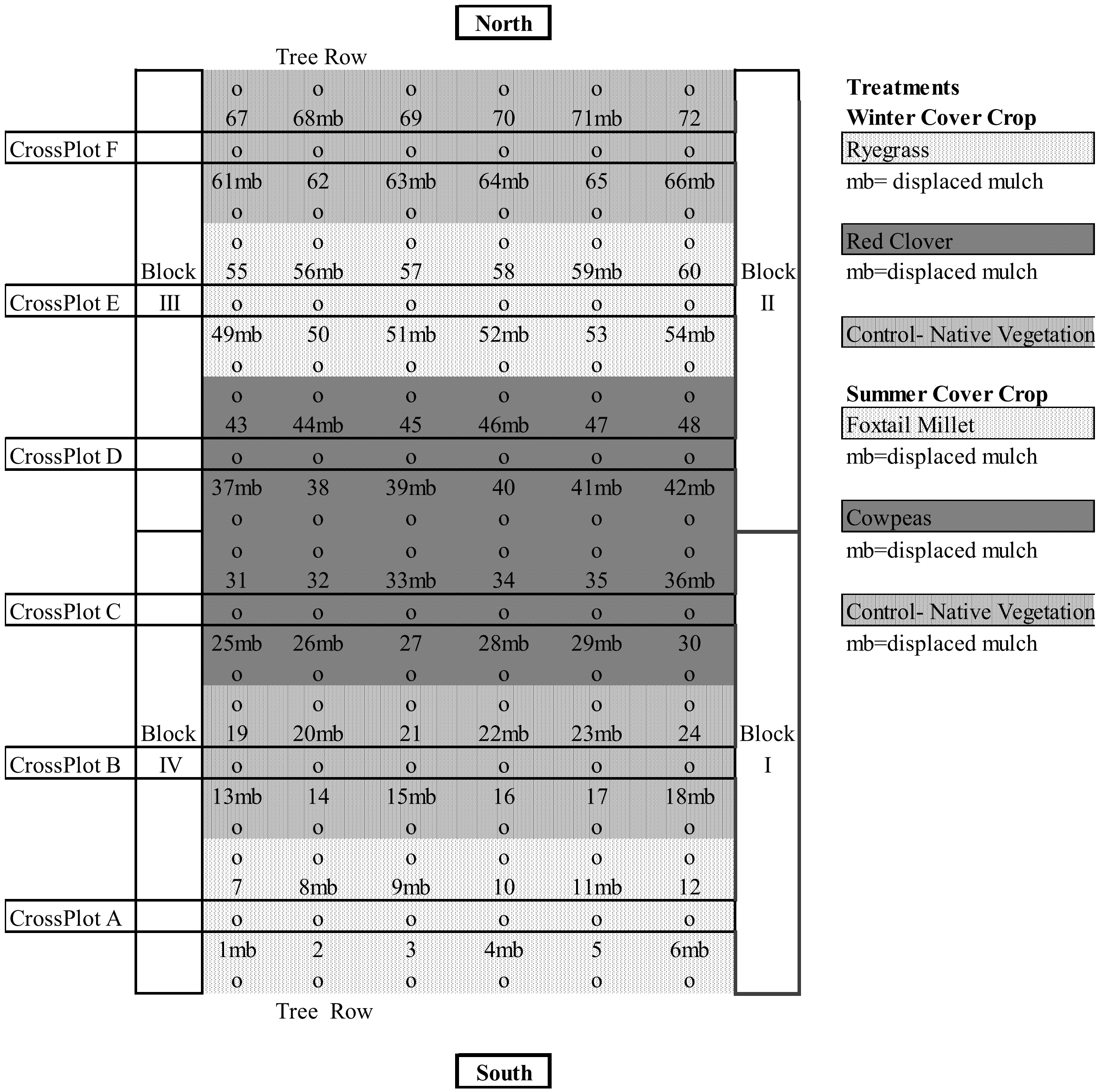
Year	Month	Avg. Min (^{O}C)	Avg. Max (^{O}C)	Min (^{O}C)	Max (^{O}C)	Mean Daily (^{O}C)	Precipitaion (cm)
November	2011	6	15	-5	23	8	17.3
December	2011	-1	10	-7	17	2	8.9
January	2012	-1	10	-9	19	2	5.6
February	2012	2	12	-12	21	4	4.8
March	2012	9	19	0	27	12	11.9
April	2012	12	23	3	30	14	5.3
May	2012	16	28	8	33	18	4.6
June	2012	19	32	9	39	22	6.4
July	2012	22	35	19	39	24	5.1
August	2012	19	32	14	39	21	10.9
September	2012	17	28	9	38	19	7.4
October	2012	8	19	-2	27	10	9.7
November	2012	3	17	-4	27	6	2.3
December	2012	2	12	-8	23	4	5.4
January	2013	-1	9	-9	21	1	6.9
February	2013	-1	9	-10	18	2	6.7
March	2013	2	12	-6	25	4	10.8
April	2013	8	19	-1	27	11	18.2
May	2013	14	23	-1	31	16	26.7
June	2013	19	29	9	36	22	3.6
July	2013	19	31	12	36	21	8.7
August	2013	19	30	11	37	21	15.5
September	2013	16	29	8	36	18	10.2
October	2013	13	27	6	29	14	8.4

http://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USC00032444/detail

Appendix A.7 *Volumetric soil water content of tree row and drive row in a newly established orchard in Fayetteville, AR, 2013*



Appendix A.8. *Plot sampling map for organic matter (OM), bulk density (BD), and Mehlich3 Nutrient Analysis in newly established orchard in Fayetteville, AR, sampled October 2011 and September 2013*



Appendix A.9 Statistical comparison of soil nutrient testing by Mehlich3 digestion for macro and micronutrients in 2011 and 2013 in an orchard in Fayetteville, AR. Testing conducted by the Soil and Foliar Testing Agricultural Service Unit, UASDOA, Altheimer Laboratory, Fayetteville, Arkansas. Sampled by cross row (east-west row divisions of an orchard with north-south tree rows- see A.7 for map). Mean separation within columns by Tukey-Kramer. Means followed by different letters are significantly different ($p \leq 0.05$). n=6

Soil organic matter

	Cross Row	Year	% OM
CrossRow*year	B	2011	4.5a
CrossRow*year	A	2011	4.3a
CrossRow*year	C	2011	3.8b
CrossRow*year	D	2011	3.7b
CrossRow*year	E	2011	3.4bc
CrossRow*year	F	2011	3.1c
CrossRow*year	A	2013	2.5d
CrossRow*year	F	2013	2.2de
CrossRow*year	B	2013	2.1de
CrossRowyear	C	2013	2.0de
CrossRow*year	D	2013	1.8e
CrossRow*year	E	2013	1.8e

Appendix A.9 (continued) Soil bulk density

	Cross Row	Year	Bulk Density
CrossRow*year	A	2011	1.24bcd
CrossRow*year	B	2011	1.23bcd
CrossRow*year	C	2011	1.37ab
CrossRow*year	D	2011	1.31abc
CrossRow*year	E	2011	1.43a
CrossRow*year	F	2011	1.46a
CrossRow*year	A	2013	1.20cd
CrossRow*year	B	2013	1.12d
CrossRow*year	C	2013	1.14d
CrossRow*year	D	2013	1.17cd
CrossRow*year	E	2013	1.19cd
CrossRow*year	F	2013	1.13d

Appendix A.9 (continued)

Soil K content			
Effect	CrossRow	Year	Estimate
CrossRow*year	D	2013	232.1a
CrossRow*year	C	2013	177.1b
CrossRow*year	B	2011	172.5b
CrossRow*year	E	2013	169.1bc
CrossRow*year	A	2013	166.6bcd
CrossRow*year	A	2011	158.7bcd
CrossRow*year	D	2011	143.3bcd
CrossRow*year	C	2011	138bcd
CrossRow*year	B	2013	129.5bcd
CrossRow*year	E	2011	123.5cd
CrossRow*year	F	2011	123cd
CrossRow*year	F	2013	118.9d

Soil P content			
Effect	CrossRow	Year	Estimate
CrossRow*year	B	2011	155.5a
CrossRow*year	B	2013	148.2ab
CrossRow*year	A	2013	134.7ab
CrossRow*year	E	2013	125.6abc
CrossRow*year	C	2013	118.5abc
CrossRow*year	D	2013	118abc
CrossRow*year	F	2013	103.8abcd
CrossRow*year	A	2011	103.2abcd
CrossRow*year	F	2011	96.7bcde
CrossRow*year	C	2011	74.5cde
CrossRow*year	D	2011	58de
CrossRow*year	E	2011	45.2e

Soil S content

Effect	CrossRow	Year	Estimate
CrossRow*year	A	2011	20a
CrossRow*year	B	2011	19.5ab
CrossRow*year	F	2011	19.4abc
CrossRow*year	B	2013	19abc
CrossRow*year	C	2011	16.8abcd
CrossRow*year	D	2011	16abcd
CrossRow*year	F	2013	15.7abcd
CrossRow*year	E	2011	15.4bcd
CrossRow*year	D	2013	15.4bcd
CrossRow*year	C	2013	15.2bcd
CrossRow*year	A	2013	15.1cd
CrossRow*year	E	2013	13.3d

Soil Ca content

Effect	CrossRow	Year	Estimate
CrossRow*year	A	2013	1026a
CrossRow*year	B	2013	1018.3a
CrossRow*year	E	2013	819b
CrossRow*year	C	2013	801.2bc
CrossRow*year	A	2011	762.5bc
CrossRow*year	B	2011	758.7bc
CrossRow*year	C	2011	743.7bc
CrossRow*year	D	2013	741bc
CrossRow*year	F	2013	691bcd
CrossRow*year	D	2011	656.7bcd
CrossRow*year	E	2011	643.3cd
CrossRow*year	F	2011	527.2d

Soil Mg content

Effect	CrossRow	Year	Estimate
CrossRow*year	A	2013	77a
CrossRow*year	D	2013	76.2a
CrossRow*year	E	2013	72.6ab
CrossRow*year	C	2013	70.8abc
CrossRow*year	B	2013	66.3abcd
CrossRow*year	D	2011	59.8bcde
CrossRow*year	F	2013	57.9bcde
CrossRow*year	B	2011	56cde
CrossRow*year	A	2011	55.5cde
CrossRow*year	C	2011	52.8de
CrossRow*year	E	2011	51.7de
CrossRow*year	F	2011	44.8e

Soil Mn content

Effect	CrossRow	Year	Estimate
CrossRow*year	F	2011	80.2a
CrossRow*year	E	2011	78.7a
CrossRow*year	F	2013	73.3ab
CrossRow*year	C	2011	66abc
CrossRow*year	D	2011	59.3bcd
CrossRow*year	E	2013	56.6cd
CrossRow*year	C	2013	53.3cd
CrossRow*year	A	2011	50.5cd
CrossRow*year	A	2013	48.8d
CrossRow*year	B	2011	47.3d
CrossRow*year	B	2013	46.9d
CrossRow*year	D	2013	46.1d

Soil Fe content

Effect	CrossRow	Year	Estimate
CrossRow*year	B	2013	94.2a
CrossRow*year	A	2013	93.2a
CrossRow*year	F	2013	91.2a
CrossRow*year	B	2011	88.5ab
CrossRow*year	C	2013	86.7ab
CrossRow*year	E	2013	84.5ab
CrossRow*year	F	2011	82.3abc
CrossRow*year	D	2013	77.9abc
CrossRow*year	A	2011	76.2abc
CrossRow*year	C	2011	69.5bc
CrossRow*year	E	2011	64.2c
CrossRow*year	D	2011	63.3c

Soil Na content

Effect	CrossRow	Year	Estimate
CrossRow*year	B	2013	10.1a
CrossRow*year	A	2013	8.3b
CrossRow*year	A	2011	7bc
CrossRow*year	C	2013	6.9bcd
CrossRow*year	E	2013	6.9bcd
CrossRow*year	F	2013	6.8bcd
CrossRow*year	B	2011	6.5cde
CrossRow*year	D	2013	5.9cdef
CrossRow*year	D	2011	5.7cdef
CrossRow*year	C	2011	5.3def
CrossRow*year	F	2011	4.9ef
CrossRow*year	E	2011	4.4f

Soil Zn content			
Effect	CrossRow	Year	Estimate
CrossRow*year	F	2013	6.5a
CrossRow*year	E	2013	6a
CrossRow*year	E	2011	5.9a
CrossRow*year	D	2011	5.9a
CrossRow*year	F	2011	5.8ab
CrossRow*year	C	2013	5.7ab
CrossRow*year	C	2011	5.6ab
CrossRow*year	B	2013	5.6ab
CrossRow*year	B	2011	5.4ab
CrossRow*year	D	2013	5.3ab
CrossRow*year	A	2013	4.5bc
CrossRow*year	A	2011	3.7c

Appendix A.10. Models for ANCOVA of Chapter 2 apple tree growth graphs.

Shoot Length in 2012. 4th degree ANCOVA with common 4th degree coefficients for treatments					
Treatment	Intercept	Date 1	Date 2	Date 3	Date 4
CP	8.19	0.55034	-0.00890	6.33649E-05	-1.45610E-07
FM	26.99	0.41288	-0.00673	5.75376E-05	-1.45610E-07
CPM	8.40	0.43815	-0.00385	4.45236E-05	-1.45610E-07
FMM	10.57	0.16189	0.00062	2.77303E-05	-1.45610E-07
NT	11.13	0.23513	-0.00149	3.77606E-05	-1.45610E-07

Shoot Diameter in 2012. Cubic ANCOVA with separate 3rd degree coefficients for treatments				
Treatment	Intercept	Date 1	Date 2	Date 3
CP	2.37	0.04714	-0.00039	1.42890E-06
FM	2.46	0.04718	-0.00036	1.44080E-06
CPM	2.51	0.03682	0.00006	-3.52200E-07
FMM	2.60	0.03022	0.00020	-9.31300E-07
NT	2.41	0.02763	0.00013	-5.56500E-07

Estimated Chlorophyll in 2012. 4th degree ANCOVA with common 4th degree coefficients for treatments					
Treatment	Intercept	Date 1	Date 2	Date 3	Date 4
CP	26.34	-27.6220	60.27720	-46.59160	13.5260
FM	26.99	-22.9982	58.91310	-46.87840	13.5260
CPM	24.56	2.6438	26.48280	-36.69130	13.5260
FMM	27.40	-15.3406	50.92140	-44.67660	13.5260
NT	22.58	-3.8799	46.05940	-44.90520	13.5260

Shoot Length in 2013. 4th degree ANCOVA with AR(1) residuals					
Treatment	Intercept	Date 1	Date 2	Date 3	Date 4
CP	14.22	0.13197	0.01428	-0.00026	1.31230E-06
FM	14.46	0.05492	0.02032	-0.00032	1.46720E-06
CPM	15.35	0.21435	0.00403	0.00007	-5.97877E-07
FMM	15.78	0.19553	0.00742	-0.00003	-3.62220E-08
NT	13.89	-0.15649	0.02268	-0.00022	7.03146E-07

Shoot Diameter in 2013. 4th degree ANCOVA with AR(1) errors					
Treatment	Intercept	Date 1	Date 2	Date 3	Date 4
CP	2.80	0.02830	0.0013	-0.00002	1.18898E-07
FM	3.05	0.02154	0.0017	-0.00003	1.26093E-07
CPM	3.19	0.01909	0.0012	-0.00001	3.54210E-08
FMM	3.27	0.00711	0.0017	-0.00002	5.77050E-08
NT	3.08	0.01157	0.0012	-0.00001	1.58970E-08

Estimated chlorophyll in 2013. Linear ANCOVA with no autocorrelation

Treatment	Intercept	Date 1
CP	31.07	-0.02961
FM	33.48	-0.10988
CPM	29.16	-0.00173
FMM	29.51	0.02058
NT	29.58	0.02045